

**PROJECT OVERVIEW REPORT
FORMER EMF SITE
KING COUNTY INTERNATIONAL AIRPORT**

**SUBMITTED TO:
WASHINGTON STATE DEPARTMENT OF ECOLOGY
VOLUNTARY CLEANUP PROGRAM**

**SUBMITTED BY:
THE BOEING COMPANY
BOEING INFORMATION SUPPORT SERVICES
ENERGY AND ENVIRONMENTAL AFFAIRS**

**PREPARED BY:
PROJECT PERFORMANCE CORPORATION
16935 SE 39TH ST. BELLEVUE, WASHINGTON**

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EXECUTIVE SUMMARY

VOLUNTARY CLEANUP PROGRAM SUBMITTAL FOR EMF SITE

The Boeing Company has completed an independent RI/FS and implementation of a Cleanup Action at a property located at 7355 Airport Way South, adjacent to the east boundary of Boeing field in Seattle, WA. Boeing currently holds a long-term lease on this property which is owned by King County International Airport (KCIA). This industrial site is a surplus Brownfield property which is no longer used by Boeing and KCIA has plans to redevelop the property for beneficial industrial use as soon as possible. Potential future industrial uses of the property are expected to be aviation/transportation related because of the prime location/access to the airport. The terms of the lease transfer back to KCIA require some letter of concurrence from Ecology regarding the Cleanup Actions implemented at the site, hence the purpose of this submittal to Ecology's Voluntary Cleanup Program (VCP).

The site currently has an operating groundwater treatment system in place. The treatment system will continue to be operated by Boeing until the cleanup goals are reached. All contaminated soil identified at the site has been removed and the surface repaved. Given the ongoing groundwater treatment at the site, this VCP submittal is not a request for a No Further Action letter. Instead, this is a request for an "in progress or opinion letter" which will allow the lease transfer to proceed and subsequent redevelopment of this Brownfield site for beneficial industrial use.

The property, referred to as the Electronic Manufacturing Facility (EMF), was utilized for manufacturing electrical circuit boards. Leaks in process piping resulted in the accidental release of trichloroethene (TCE) to soil. Operations were discontinued in the late 1970's and contaminated soil was discovered in the mid 1980's. Initial removal actions at that time addressed contaminated soil where feasible, but some areas (near and under foundation footings) were inaccessible because soil removal could result in the collapse of the building. Several groundwater monitoring wells were installed throughout the site at that time and subsequently have been monitored regularly for the last 13 years. In 1996 the building was demolished down to the floor slab and a more detailed site investigation initiated. The RI/FS and implementation of a Cleanup Action have been completed in accordance with MTCA requirements and guidance from Ecology's Independent Remedial Action Program (IRAP).

The RI delineated the extent of the solvent plume in groundwater (primarily TCE and decay products resulting from reductive dechlorination) and two areas with TPH contamination in soil. The solvent plume covers a limited area approximately 200 feet long by 150 feet wide and has been stationary for the 13 years of groundwater sampling. Qualitative and quantitative data demonstrate that natural attenuation through reductive dechlorination has effectively contained the VOC plume in its present location :

- Groundwater flow is over 200 ft/yr whereas the VOC plume has only migrated 200 feet in 20 years
- The groundwater conditions are a strongly reducing environment (low redox potential, low dissolved oxygen levels, and elevated Fe(II))
- Expected TCE degradation products of *cis*-1,2 DCE and vinyl chloride are present down gradient from the source (the presence of *cis*-1,2 DCE is a distinct marker of TCE degradation

- processes because it is not a manufactured substance)
- Wells located in the down-gradient VOC plume (in the range of 50 to 150 feet from the source) have chloride concentrations about 600 % higher than background wells as a result of the TCE degradation by reductive dechlorination
- Down-gradient monitoring wells (about 200 feet from the source) show complete dechlorination (i.e, TCE, DCE and vinyl chloride are reduced to levels in the range of ND-3 ppb)
- Based on site conditions and plume distribution, the first-order degradation rate for TCE is estimated to be 2.8 1/yr (a half life of 0.25 years)

The risk assessment completed in the RI/FS identified the reasonable maximum exposure for groundwater as discharge to surface water in the Duwamish river (approximately 4000 feet from the plume and 2000 from the property boundary). Groundwater at the site is not a potable resource for the following reasons:

- Groundwater in the area of the site does not serve as a current drinking water source.
- The groundwater flow direction is directly/immediately under the airport, across Boeing Plant 2 property to ultimate discharge in the Duwamish river which is not suitable for domestic water supply. Boeing and KCIA control all property in the groundwater pathway from the site to the Duwamish river.
- Groundwater at this site will not migrate to other current/potential future sources of drinking water.
- A water supply well is not compatible with airport operations (continuous fueling operations activities).
- Installation of a water supply wells is prohibited based on state regulations (WAC 173-160-171).
- A water supply well is not allowed under King County Board of Health Title 12, section 112.24.010a (higher quality sources are available and water supply wells are required to draw water from at least 50 feet deep and below at least one impermeable confining layer).
- Municipal water supply is available on site, KCIA will not allow installation of supply wells.

Based on the reasonable maximum exposure for groundwater, cleanup levels for groundwater established in the RI/FS have been based on applicable surface water quality criteria. The specific standards for protection of beneficial use of surface water are from EPA's Water Quality Criteria Guidance. The cleanup goals are:

- Trichloroethene—45 mg/l based on the Lowest Observed Effects Level (LOEL) set by EPA (Federal Register Notice 45 FR 79341, no ambient chronic or acute criteria exist for this compound).
- 1,2 Dichloroethene—11.6 mg/l based on the LOEL set by EPA (Federal Register Notice 45 FR 79332 no ambient chronic or acute criteria exist for this compound).
- Vinyl Chloride —0.525 mg/l based on the ambient criteria for human-health fish consumption set by EPA (Federal Register Notice 45 FR 79341, no ambient chronic or acute criteria or LOELs exist for this compound).

The conditional point of compliance for these cleanup levels is the property boundary. Existing monitoring wells (MW-2, MW-5, and MW -4) located immediately down gradient of the VOC plume will be used for performance monitoring. These wells have an existing 13 year record of monitoring data and are located approximately 2,000 feet up gradient from the property boundary.

The groundwater remediation technology selected in the RI/FS and implemented in the Cleanup Action is an in-well stripping technology. This technology, although comparatively new and innovative, is a proven technology that has been implemented successfully at several hundred groundwater contamination sites. Examples include the Pasco landfill CERCLA site, Massachusetts Military Reservation in one of the largest groundwater cleanup projects in the US, and the technology will be implemented in the summer of 1998 at the Boomsnub/BOC CERCLA site in Vancouver, WA.

The in-situ treatment system is laid out with one treatment well in the hot spot of the plume and a second treatment well located about 100 feet down gradient to provide additional treatment and containment of any further plume migration. The expected diameter of the treatment/capture zone established by the down-gradient treatment well is 150+ feet which is greater than the plume width at that location. Performance monitoring during system startup and operations has demonstrated effective capture and containment of the plume by the down-gradient treatment well. The treatment system has been operating for approximately 5 months. Over this initial operating period, the system has removed over 400 lbs of TCE from the site groundwater (the RI estimated that a total of 600 lbs of TCE were present in dissolved and nonaqueous phase form). TCE concentrations in the hot-spot well have been reduced by 57% during this initial operating period. In down-gradient performance monitoring wells located within the treatment zone, TCE concentration reductions have ranged from 96% to 99.8%.

Boeing is currently monitoring site groundwater and system operational parameters. Routine monitoring will continue through the system operating period. Following system shutdown when the cleanup goals are reached, the frequency of the monitoring program will be reduced.

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Appendix B: Analytical Results from Recent Groundwater Sampling Events

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Attachment 2 Weston 1997a. Remedial Investigation/Feasibility Study, Former Electrical Manufacturing Facility, King County International Airport (June 27, 1997)

Attachment 3 Weston 1997b. Independent Remedial Action, Cleanup Action Plan, Former Electrical Manufacturing Facility, King County International Airport (April 17, 1997)

Attachment 4 Weston 1997c. Remedial Action Report, Independent Remedial Action Program, Former Electrical Manufacturing Facility, King County International Airport (August 7, 1997)

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1.0 Introduction

This project overview report has been prepared to summarize the site investigation and remedial actions completed by The Boeing Company at the Former Electronic Manufacturing Facility site located at 7355 Airport Way South, adjacent to the east boundary of King County International Airport (KCIA) in Seattle, WA. The site investigation and cleanup actions completed at the site have been undertaken to satisfy the requirements of the Model Toxics Control Act (MTCA) set forth in WAC 173-340. The industrial property is owned by KCIA and leased to Boeing. The site is no longer used by Boeing and KCIA has plans to redevelop the property. Future industrial uses of the property are expected to be aviation/transportation related. The terms of the lease transfer back to KCIA require some letter of concurrence from Ecology regarding the Cleanup Actions implemented at the site.

The initial site investigations, Remedial Investigation/Feasibility Study (RI/FS), Cleanup Action Plan (CAP), and Remedial Action Report(RA) encompass several large reports with an abundance of site characterization and design information. These site reports are included as attachments to this submittal. This report provides an overview summary of information presented in the existing reports along with additional information on the remedial actions completed, performance of the treatment system and continued site monitoring since the prior reports were completed.

1.1 Purpose

The purpose of this submittal is to request a technical review and concurrence under Ecology's Voluntary Cleanup Program (VCP). Since the site has ongoing groundwater treatment, this VCP submittal is a request for an "in progress or opinion letter" which will allow the lease transfer to proceed.

The purpose of this project overview report is to summarize all available information from the existing project reports (initial investigations, RI/FS, CAP, and RA report), current site monitoring data and performance of the remedial measures in place at the site. This overview report has been prepared to provide the most current site information and a brief guidebook or "road map" to the salient information included in the other site reports.

1.2 Organization

The combined information presented in this overview summarizes the following key areas (from prior site reports and new monitoring data):

- Section 2, Site history
- Section 3, Risk assessment
- Section 4, Remedial investigation/sampling
- Section 5, Observed attenuation processes
- Section 6, Feasibility study

- Section 7, Remedial actions for soil
- Section 8, Remedial actions for groundwater

The information is presented in a short one-page summary format (with additional figures as appropriate) for each of the relevant topics. References to the background source documents (RI/FS, CAP, RA report, EPA Criteria documents, etc.) are provided to direct the reader to more detailed information as required.

Appendices included in this project summary report present additional site information on the following topics:

- Appendix A: Site Maps with Recent Groundwater Monitoring Results
- Appendix B: Analytical Results from Recent Groundwater Sampling Events
- Appendix C: Background Information on In-Well Stripping Technology

Attachments to this project summary report present the prior site investigation and cleanup action reports:

- 1) Landau 1993. 1993 Groundwater Monitoring Former EMF Facility (May 18, 1993)
- 2) Weston 1997a. Remedial Investigation/Feasibility Study, Former Electrical Manufacturing Facility, King County International Airport (June 27, 1997)
- 3) Weston 1997b. Independent Remedial Action, Cleanup Action Plan, Former Electrical Manufacturing Facility, King County International Airport (April 17, 1997)
- 4) Weston 1997c. Remedial Action Report, Independent Remedial Action Program, Former Electrical Manufacturing Facility, King County International Airport (August 7, 1997)

2.0 Site History

This summary of site history is taken from the initial site investigation reports (Landau 1993), the RI/FS (Weston 1997a) and other sources. The relevant chronological history at the site includes the following key elements.

From the 1930's to late the 1950's the site was used for used for two aircraft hangers.

From the mid 1960's to the late 1970's the site was used for electronic circuit board manufacturing (including the use of TCE for cleaning of circuit boards).

Electronic circuit board manufacturing at the site was discontinued in the late 1970's.

In early 1980's, removal of tanks and solvent baths indicated release of solvents to soils.

Monitoring wells were installed in 1985: groundwater monitoring has been conducted for 13 years (first quarterly, then semi-annually, then annually & most recently quarterly).

Ecology rescinded consent order related to site contamination (Stipulation and Order of Dismissal, Pollution Control Hearing Board 85-71. December 12, 1985)

The monitoring program detected solvents in groundwater (TCE, and degradation by-products *cis*-1,2 DCE and vinyl chloride).

The VOC plume covers an area approximately 200 feet long by 150 feet wide.

The down-gradient boundary of the VOC plume is defined by 2 monitoring wells which have consistently been in the range of ND to 5 ppb for VOCs (based on monitoring for 13 years).

The building at the site was removed in 1996.

Additional investigations were completed in 1996 as part of the RI (extensive Geoprobe and soil sampling, soil and groundwater samples analyzed for VOCs, Semi-VOAs, TPH, pesticides, PCBs and total metals).

The RI/FS was completed in 1997.

The remedial actions were implemented in 1997 including:

- Soil; excavation and disposal (primarily TPH hot spots from former tank locations) in spring of 1997.

- Groundwater; in-well stripping system installed in hot spot and down-gradient area of the plume in fall of 1997.

3.0 Risk Assessment Summary

This summary of the site risk assessment is taken from the RI/FS (Weston 1997a). The intent of a risk assessment under the MTCA is to identify reasonable maximum exposures (RME) for affected media (soil and groundwater at this site) and set cleanup goals which are protective of human health and the environment (as opposed to a baseline risk assessment).

Soil;

The site is zoned for industrial land use and the surface is capped. All areas exceeding MTCA Method A standards were excavated and removed.

Groundwater;

- a. Groundwater in the area of the site does not serve as a current drinking water source.
- b. The groundwater flow direction is directly/immediately under the airport, across Boeing Plant 2 property to ultimate discharge in the Duwamish river which is not suitable for domestic water supply. Boeing and KCIA control all property in the groundwater pathway from the site to the Duwamish river.
- c. Groundwater at this site will not migrate to other current/potential future sources of drinking water.
- d. A water supply well is not compatible with airport operations (continuous fueling operations activities).
- e. Installation of a water supply wells is prohibited based on state regulations (WAC 173-160-171).
- f. A water supply well is not allowed under King County Board of Health Title 12, section 112.24.010a (higher quality sources are available and water supply wells are required to draw water from at least 50 feet deep and below at least one impermeable confining layer).
- g. Municipal water supply is available on site, KCIA will not allow installation of supply wells.

The reasonable maximum exposure for non-potable water is protecting the beneficial use of surface water.

3.1 Summary of EPA Criteria Documents for TCE, DCE and Vinyl Chloride

Section 304 of the Clean Water Act requires the EPA to publish water quality criteria reflecting the latest scientific knowledge on the nature and extent of all identifiable effects that chemicals in any body of water may have on human health and the aquatic environment. Pursuant to this requirement EPA, has published ambient water quality criteria (AWQC) documents for TCE, DCE and vinyl chloride. The relevant AWQC documents for TCE, DCE and vinyl chloride were published by the EPA in 1980 (EPA 1980a, 1980b and 1980c). Under the MTCA (chapter 173-340-730 WAC), surface water cleanup standards are to be based on water quality standards for the state of Washington (chapter 173-201 WAC) and water quality criteria published pursuant to section 304 of the Clean Water Act.

All of these compounds are quite volatile and are expected to be rapidly eliminated from surface water through volatilization. The EPA criteria documents note that these compounds will be quickly transferred from aquatic systems to the atmosphere through volatilization and studies have shown that these compounds should not remain in an aquatic ecosystem under most natural conditions. Due to the relative solubility (~ 1,100 mg/L for TCE, 2,500 mg/L for 1,2-DCE, and 2,600 mg/L for vinyl chloride) of these compounds, they are not bioaccumulated to any significant degree and the half life of these compounds in biological tissues is less than one day.

Trichloroethene

The criteria document states that available data for TCE indicate that toxicity to freshwater aquatic life has been observed at concentrations as low as 45 mg/l. No data are available concerning chronic toxicity to sensitive freshwater aquatic life but adverse behavior effects (not toxic effects) occur in one species at a concentration as low as 21.9 mg/l.

Dichloroethene

The criteria document states that available data for DCE indicate that toxicity to freshwater aquatic life has been observed at concentrations as low as 11.6 mg/l. No definitive data are available concerning chronic toxicity to sensitive freshwater aquatic species. Most of the aquatic studies for DCE have been conducted with 1,1-DCE isomer. One study testing bluegills found the 96-hour LC₅₀ for 1,1-DCE and 1,2-DCE to be 73.9 and 135 mg/l, respectively. The criteria document notes that the location of the chlorine atoms on the DCE molecule (1,1-DCE versus 1,2-DCE) does not affect the acute toxicity very much (for freshwater aquatic species).

Vinyl Chloride

The criteria document states that insufficient data exist for vinyl chloride toxicity to set criteria for aquatic species. One bacterial growth test indicated that vinyl chloride was not toxic (to bacteria) at concentrations up to 900 mg/L. Based on an estimated bioconcentration of vinyl chloride in fish, the criteria document states that a concentration of 0.525 mg/L would be protective of human health based on exposure from fish consumption (at a risk level of 10⁻⁶).

3.2 Applicable Surface Water Standards for Beneficial Use of Surface Water

Compound	Water quality criteria	Basis	Federal Register reference
TCE	45 mg/l	LOEL ¹	45 FR 79341
1,2 DCE	11.6 mg/l	LOEL ¹	45 FR 79332
vinyl chloride	0.525 mg/l	² Ambient criteria for human health risk consumption	45 FR 79341

¹EPA criteria documents use Lowest Observed Effects Limit (LOEL) for these compounds

²No LOEL exists for this compound

4.0 Summary of Remedial Investigation/Sampling

This summary of investigations and sampling at the site is taken from the initial site investigation reports (Landau 1993), the RI/FS (Weston 1997a), and subsequent sampling events.

Initial identification of contamination

Initial groundwater sampling wells were installed in 1985 (9 wells sampled for ~ 13 years starting in 1985, sampling between 2 and 3 times/year, analyzed for VOCs and metals)

RI Phase (demolition of the building in 1996 allows access for investigation)

The RI was focused to delineate known/suspected areas of contamination (removed UST, above ground storage tanks, sumps)

Soil characterization: 32 soil borings, with chemical analysis of soil samples including the following; 29 samples for VOCs, 24 samples for metals, 30 samples for TPH, 20 samples for PCBs (see appendices A and C of RI/FS).

Two soil core samples of the aquitard zone (present from 40 to 50 ft bgs) indicated a hydraulic conductivity of approximately 3×10^{-7} cm/s for this unit (see appendix B of RI/FS)

Groundwater characterization (see Figure 4-1 for groundwater sampling locations)

29 Geoprobe sampling locations (multiple samples collected at different elevations)

3 samples for metals, 4 samples for TPH, 54 samples for VOCs (see Figures 4-2, to 4-5 for baseline groundwater plume maps, and appendix C of RI/FS for data). The data presented in Figures 4-2 to 4-5 represent conditions before the remediation system was installed in 1997 (see recent monitoring data in Appendix A for current site conditions).

9 wells (sampled over two sampling events)

9 samples for metals, 18 samples for VOCs

The RI included two Geoprobe sampling locations below the aquitard zone, the analytical results from those samples indicated all VOCs to be at non-detect (ND) levels

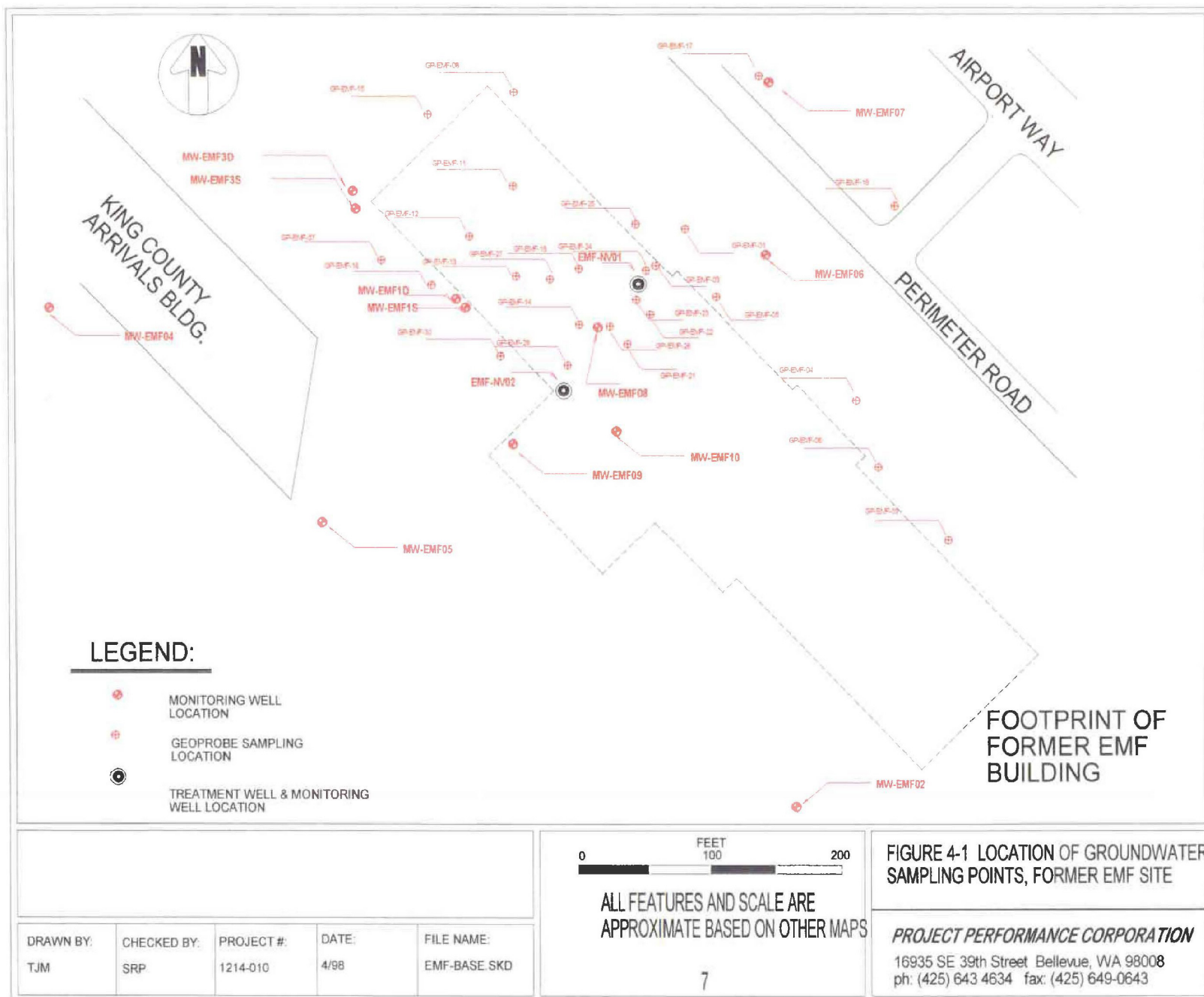
Sampling Associated with Remediation System Installation and Operation

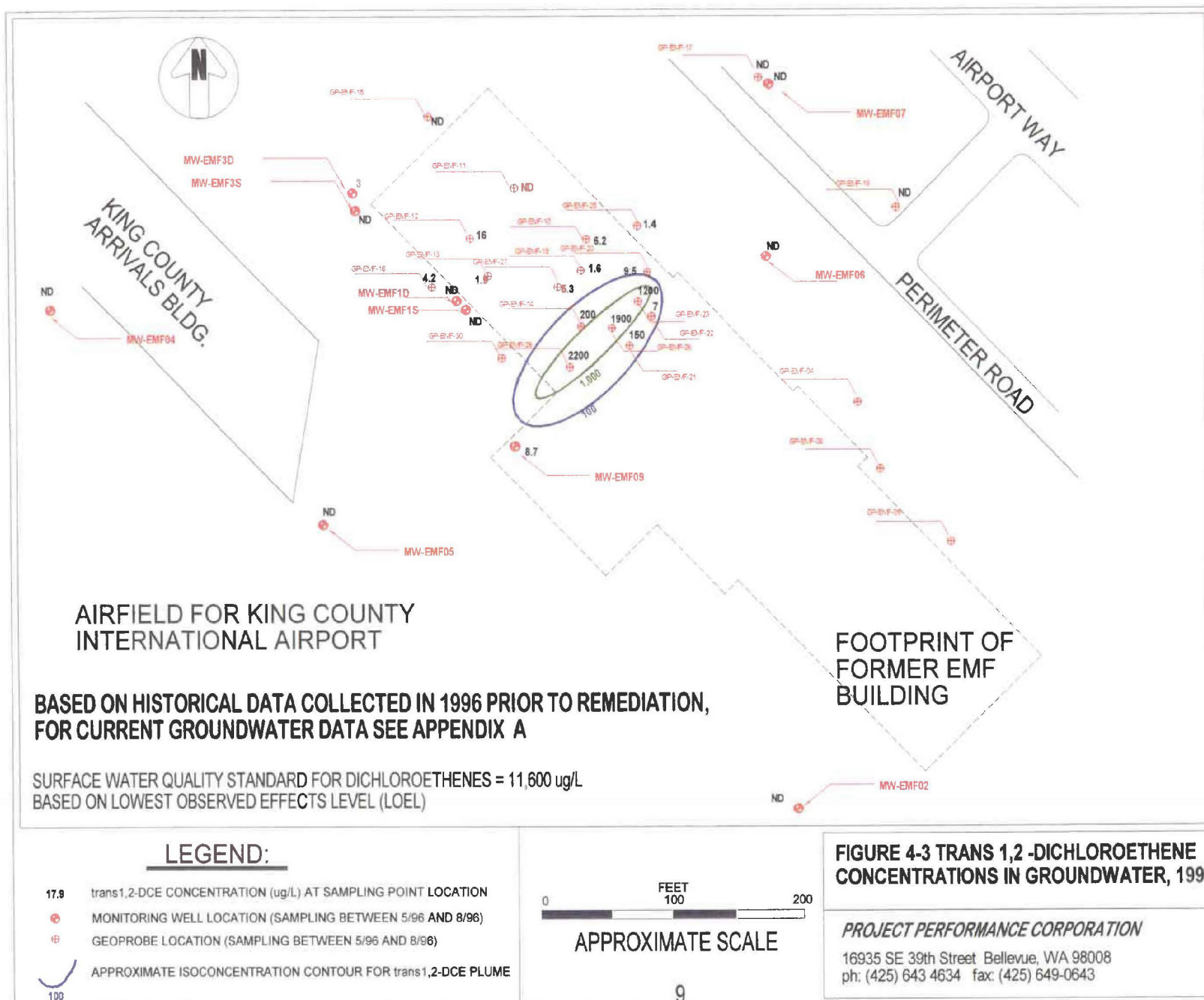
5 new monitoring wells installed (in addition to existing 8 wells)

3 monitoring events (one before startup, 3 weeks after startup, and after 3 months of operation)

42 samples for VOCs (see figures and tables in Appendices A and B of this report for data)

Regular measurements of off-gas VOC concentration (for carbon change-out and mass removal rates)

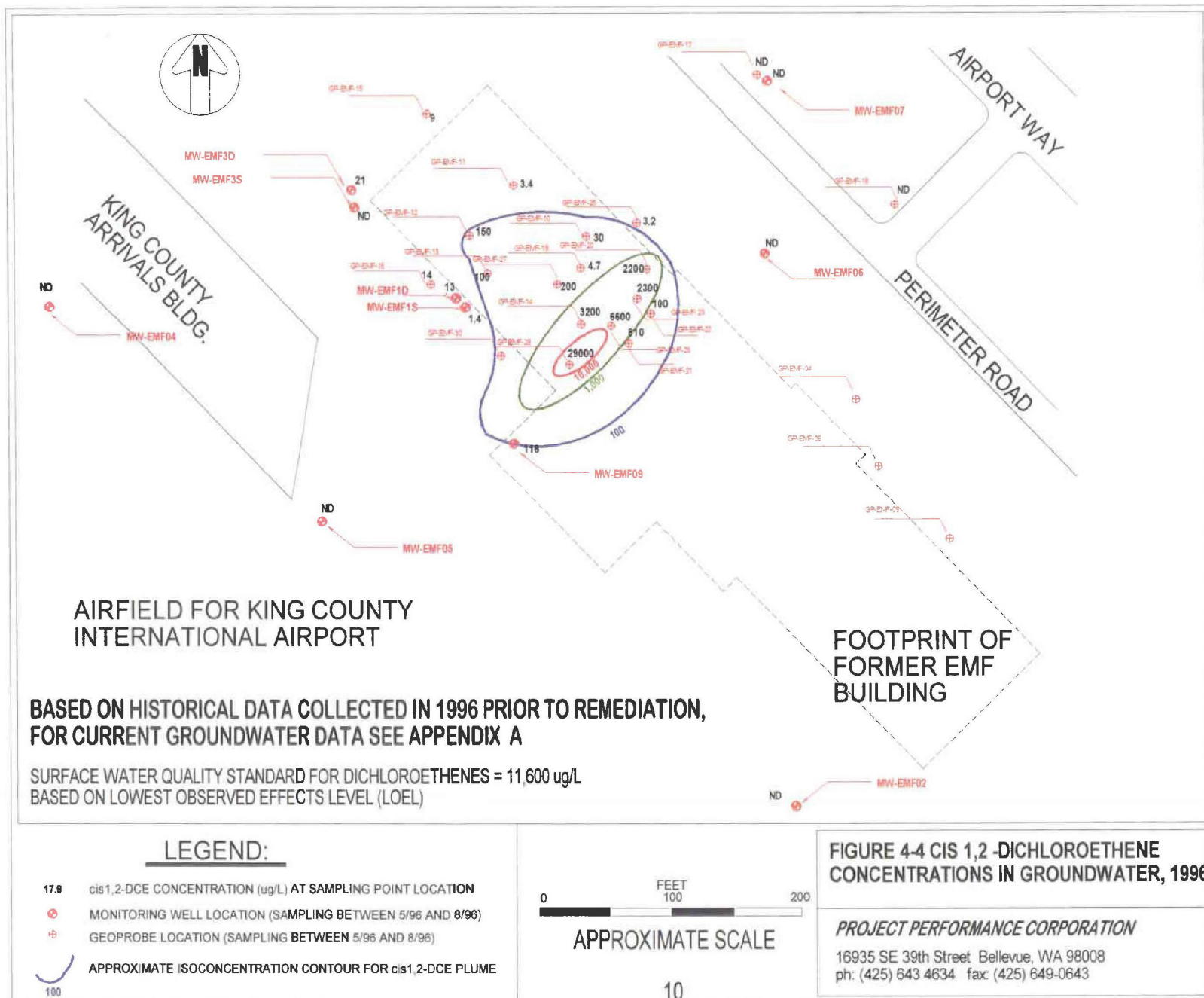


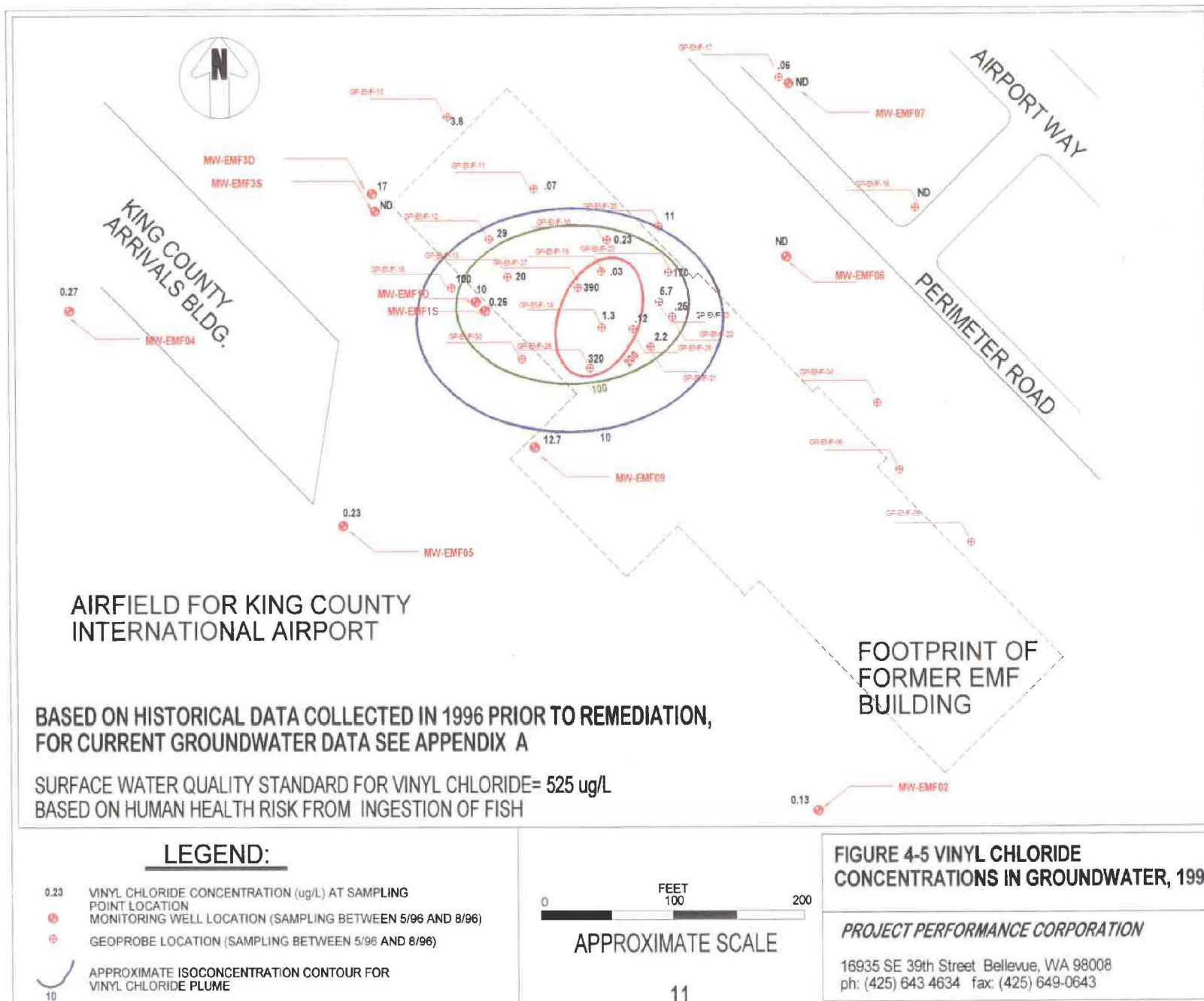


**BASED ON HISTORICAL DATA COLLECTED IN 1996 PRIOR TO REMEDIATION,
 FOR CURRENT GROUNDWATER DATA SEE APPENDIX A**

**SURFACE WATER QUALITY STANDARD FOR DICHLOROETHENES = 11,600 ug/L
 BASED ON LOWEST OBSERVED EFFECTS LEVEL (LOEL)**

APPROXIMATE SCALE





5.0 Observed Attenuation Processes at EMF Site

This summary of degradation processes for TCE at the site is based on data from the initial site investigation reports (Landau 1993), the RI/FS (Weston 1997a), subsequent sampling events, and directives from EPA regarding evaluation and characterization of degradation of chlorinated compounds (EPA 1997).

Plume Migration:

The estimated groundwater flow velocity is ~200 ft/yr (based on a conductivity of 28 ft/dy [10^{-2} cm/s], a measured gradient of 0.005, and a porosity of 0.25). The plume travel time since the time of release is at least 18 years and more likely ~25 years. Assuming no degradation processes, the predicted plume migration is between 3,500 ft and 5,000 (across the airport, past Boeing Plant 2 facilities and to the Duwamish river).

The actual plume migration has been about 200 ft from point of release over 18 to 25 years. The plume distribution is stable (seasonal/sampling variations exist), 13+ years of down-gradient monitoring have shown no changes.

Degradation Products:

Expected TCE degradation products of *cis*-1,2 DCE and vinyl chloride are present down gradient from the source (the presence of *cis*-1,2 DCE is a distinct marker of TCE degradation processes because it is not a manufactured substance)

Down-gradient monitoring wells (about 200 feet from the source) show complete dechlorination (i.e, TCE, DCE and vinyl chloride are reduced to levels in the range of ND-3 ppb)

Wells located in the down-gradient VOC plume (in the range of 50 to 150 feet from the source) have chloride concentrations about 600 % higher than background wells as a result of the TCE degradation by reductive dechlorination.

The groundwater is a strongly reducing environment (low redox potential, dissolved iron, Fe (II), is present, low dissolved oxygen levels)

Degradation Rate:

Based on site conditions and plume distribution, the first-order degradation rate for TCE is estimated to be 2.8 1/yr (a half life of 0.25 years). This value is at the low end of reported TCE degradation rates under anaerobic conditions (Howard et al. 1991). See the predicted plume distribution maps (Figure 5-1 Centerline of plume with and without degradation including field data, Figure 5-2 Plume distribution without degradation, 5-3 Plume distribution with degradation). For the case without degradation, the predicted TCE concentrations are about 4 to 5 orders of magnitude higher than are actually present in down-gradient wells)

FIGURE 5-1. EMF Site Transport Modeling, Centerline of Plume: Comparison of No Degradation, 1st Order Decay, and Field Data

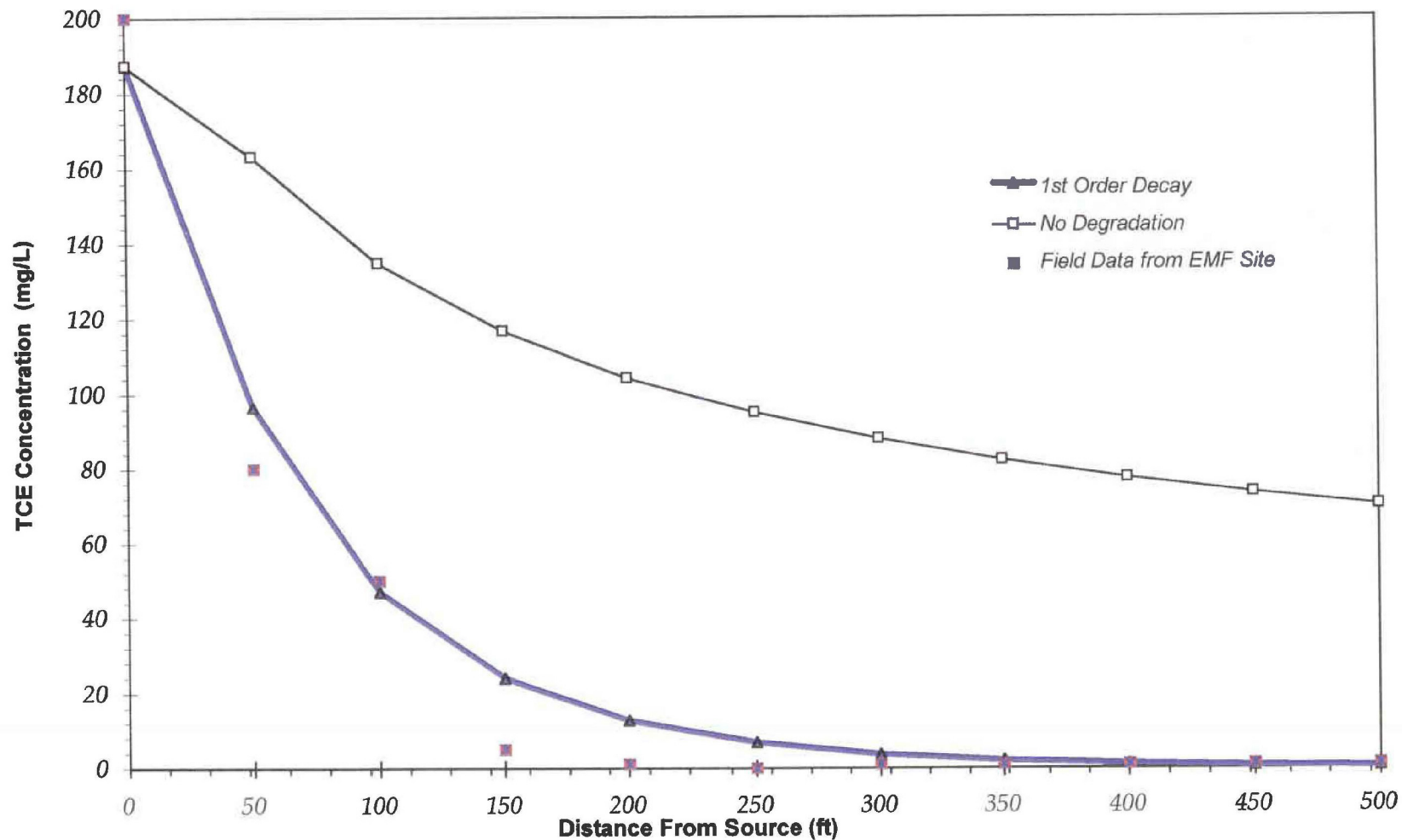
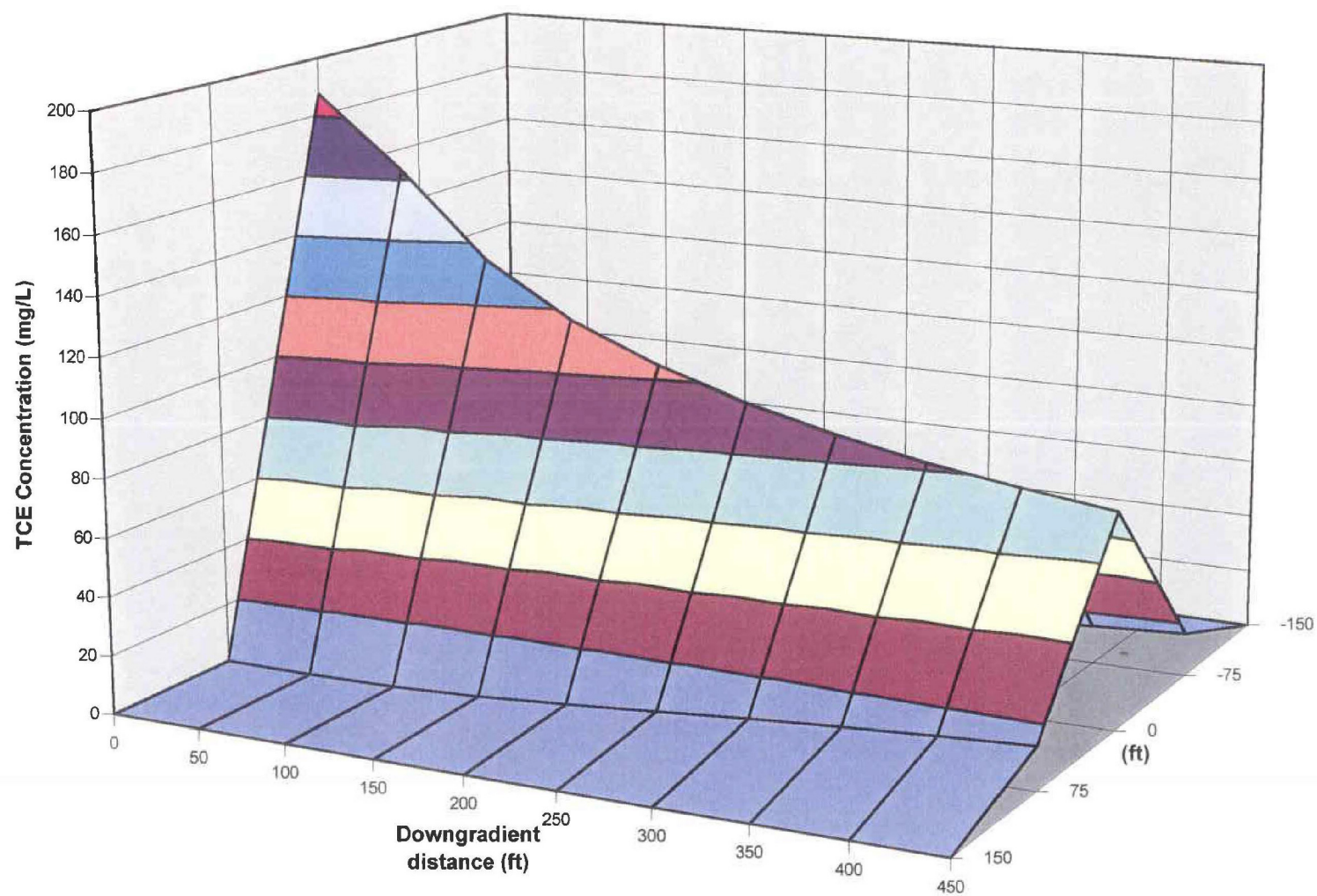
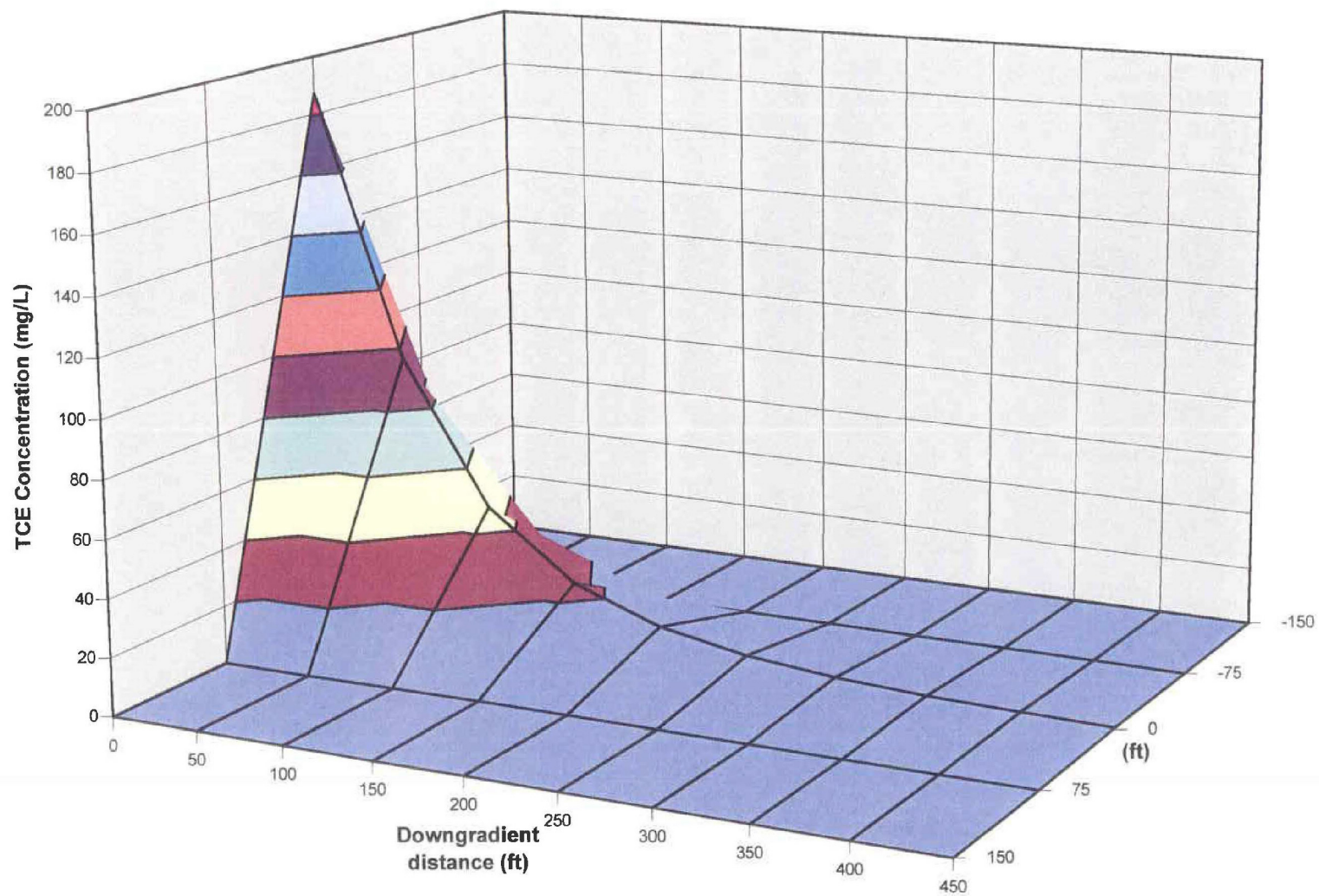


FIGURE 5-2 EMF Site Transport Modeling: Predicted TCE Plume Distribution without Degradation
 (see Figure 5-1 for comparison with field data)



**FIGURE 5-3 EMF Site Transport Modeling: Predicted TCE Plume Distribution with Degradation
(TCE half life of 0.25 yrs, see Figure 5-1 for comparison with field data)**



6.0 Summary of Feasibility Study

This summary of the feasibility study is taken from the RI/FS (Weston 1997a). The feasibility study for selection of cleanup actions was completed following the MTCA guidance (WAC 173-340-360).

Soil Remediation

Excavation with off-site disposal was chosen as a presumptive remedy for the limited areas of soil contamination present at the site. This remedial action meets the threshold requirements:

- protect human health and the environment
- comply with cleanup standards
- comply with ARARs
- provide for monitoring

This action also ranks favorably for all of the other screening criteria included under the MTCA.

Groundwater Remediation

An initial screening evaluation examined several in-situ and ex-situ treatment processes. Containment technologies, such as a slurry wall, were eliminated in screening due to the desire to remove solvents from groundwater and the fact that effective containment is already provided by existing natural attenuation processes (reductive dechlorination of TCE and by products).

Following the initial screening, three technologies for groundwater were considered in more detail:

- 1) Extraction and treatment with UV oxidation
- 2) Extraction and treatment with air stripping and activated carbon for off-gas
- 3) In-situ treatment using in-well stripping with activated carbon for off-gas

These three alternatives were evaluated and ranked relative to the MTCA selection criteria. All three alternatives met the required threshold criteria. Bids were solicited from several vendors to provide the cost estimates used in the feasibility study. In-situ treatment using in-well stripping was ranked the most preferable option based on an evaluation of the remaining MTCA selection criteria.

7.0 Summary of Remedial Actions for Soil

Summary of prior tank removal/soil removal actions:

- 1) October 1982, chromium contaminated soil was identified and excavated. Ecology was notified and provided oversight. A total of 36 yds of soil were removed. Additional soil and groundwater sampling were conducted during the RI.
- 2) March 1986, tank PL-206, 2000 gallon Bunker C fuel tank, 65 yds of soil removed, the excavation was backfilled with Ecology concurrence. Additional soil and groundwater sampling were conducted during the RI.
- 3) March 1986, tank PL-204, 110 gallon gasoline tank, no leakage, hole backfilled. Additional soil and groundwater sampling were conducted during the RI.
- 4) April 1986, concrete around former chromic acid tank (PL-205), chrome found in soil, 20 yds of soil removed, hole backfilled with Ecology concurrence. Additional soil and groundwater sampling were conducted during the RI.
- 5) April 1986, tank PL-207, 1500 gallon tank diesel, 80 cubic yds of soil were removed and the excavation backfilled. Additional soil and groundwater sampling were conducted during the RI.
- 6) August 1986, tank PL-203, 3000 gallon tank diesel, no leakage, excavation backfilled. Additional soil and groundwater sampling were conducted during the RI.
- 7) August 1986, spill retention basin within compressor house, 72 yds of soil removed, results of soil samples submitted to Ecology.

Soil Removal Actions in Cleanup Action Following RI/FS:

- 1) May 1997, soil was removed in 3 areas with elevated TPH levels, total removal of 35 yds. Sampling from sidewalls of excavations verify that TPH levels were below MTCA method A standards (see data in Table 2-3 of RA report).
- 2) May 1997, soil removal for construction of treatment wells (infiltration galleries) 105 yds.

Total Soil Removal Actions:

413 yds of soil were removed and disposed of off-site.

Capping:

The entire site was repaved with new storm water runoff collection system.

Completion of Remedial Actions for Soil:

The RI and Cleanup Actions have included extensive sampling of all areas suspected to have soil contamination. The soil removal actions have removed (with off-site disposal) all soil with contamination exceeding MTCA Method A standards. The confirmational sampling (either as part of the RI or sampling from sidewalls of excavations during removal actions) have verified that all areas with soil contamination have been remediated to levels below MTCA Method A standards.

8.0 Summary of Remedial Actions for Groundwater

The feasibility study selected in-well stripping as the preferred remedial technology for groundwater contamination. Background information on this technology is presented in Appendix C to this report. The Cleanup Action Plan (Weston 1997b) provides general design details for the system installed. Additional details of system performance (TCE mass removal and TCE concentration reductions) at this site are presented in this section.

In-well stripping system for groundwater remediation (see Figure 8-1 for typical well design)

Two treatment wells were installed; one well is located at the hot spot for source removal, including separate free-phase NAPL recovery and the second is located near the down-gradient end of the plume for added treatment/containment. The diameter of treatment/capture zone is measured at ~ 150 feet based on measured concentration reductions and drawdown in performance monitoring wells (see Figures 8-2, 8-3 and 8-4).

Performance Data

TCE mass removal (see Figure 8-5)

Free phase TCE recovered, 26 liters (80 lbs)

TCE vapor recovery ~ 400 lbs of TCE (removed via activated carbon)

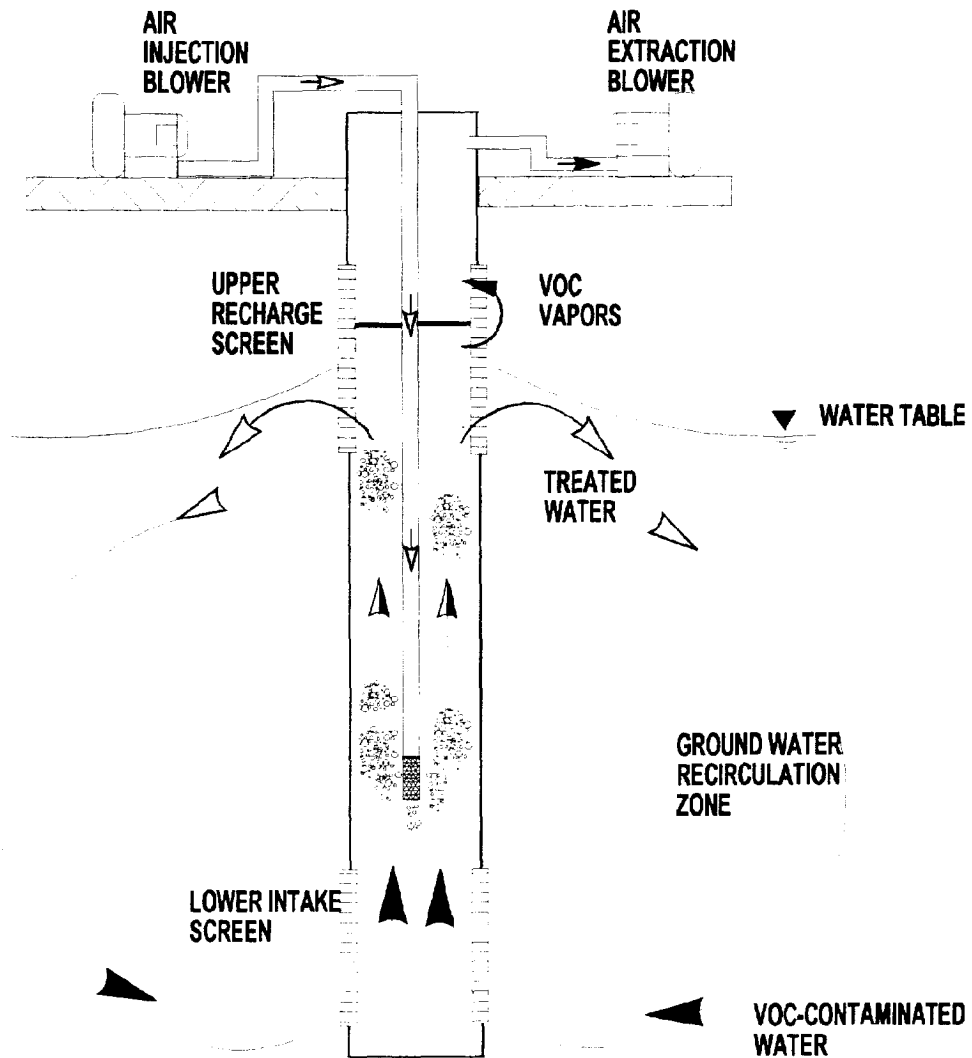
Current mass removal rate ~2- 3 lbs/day of TCE

TCE concentration reductions

TCE in hot spot well has decreased by 57%

TCE in performance monitoring wells within plume has shown 96 to 99+% concentration reductions (MW-8, MW-9, MW-10 see Figure 8-2)

DCE and VC concentrations have been up and down (typically several orders of magnitude less than TCE levels)



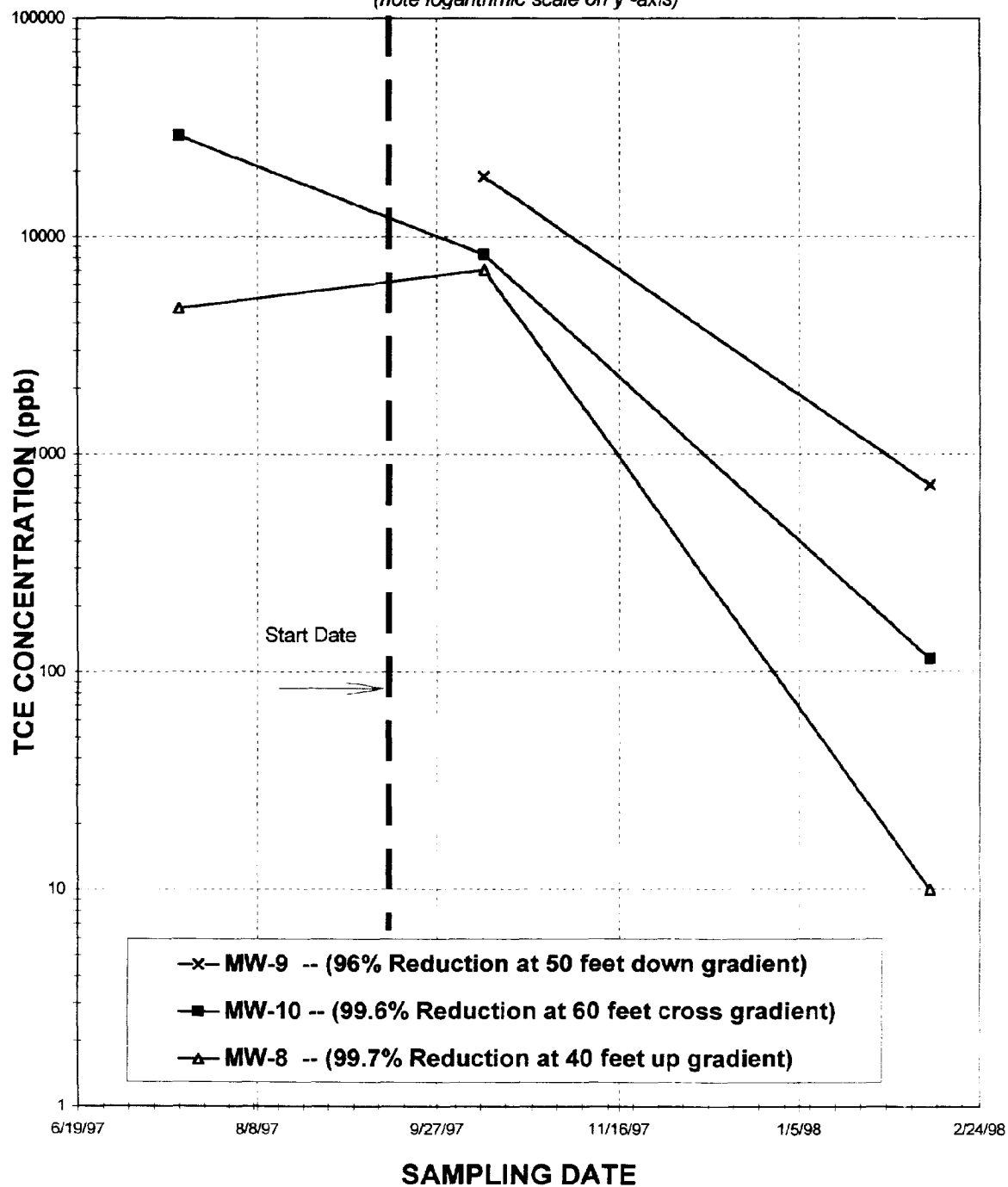
- ▷ UNCONTAMINATED WATER/AIR
- ▷ WATER-AIR MIXTURE
- ▷ CONTAMINATED WATER/VAPOR

FIGURE 8-1. TYPICAL LAYOUT OF IN-WELL STRIPPING SYSTEM IN A RECIRCULATING WELL

PROJECT PERFORMANCE CORPORATION
16935 SE 39th STREET BELLEVUE WA 98008

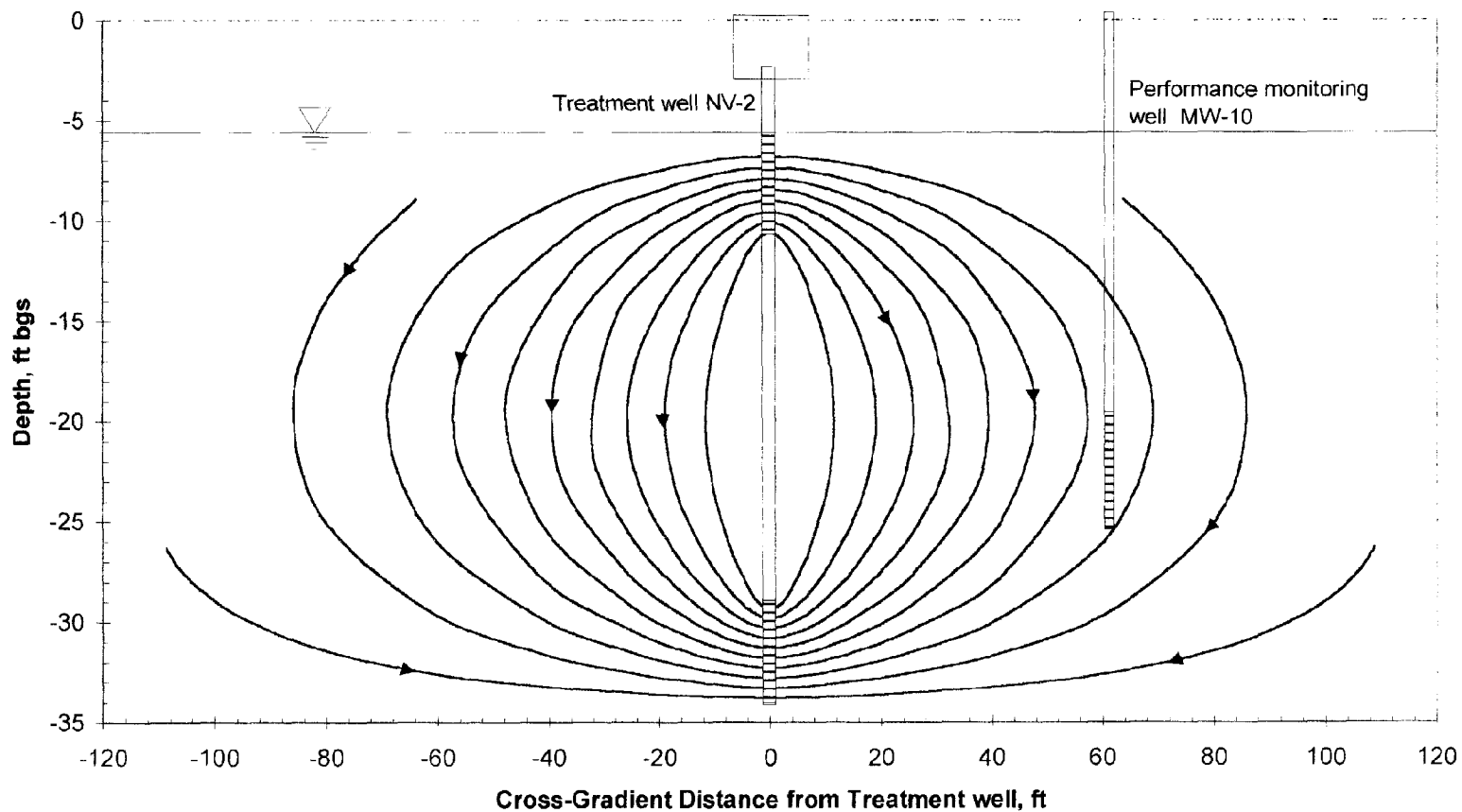
**Figure 8-2 Observed TCE Concentration Reductions
in Performance Monitoring Wells, Former EMF Site**

(note logarithmic scale on y-axis)



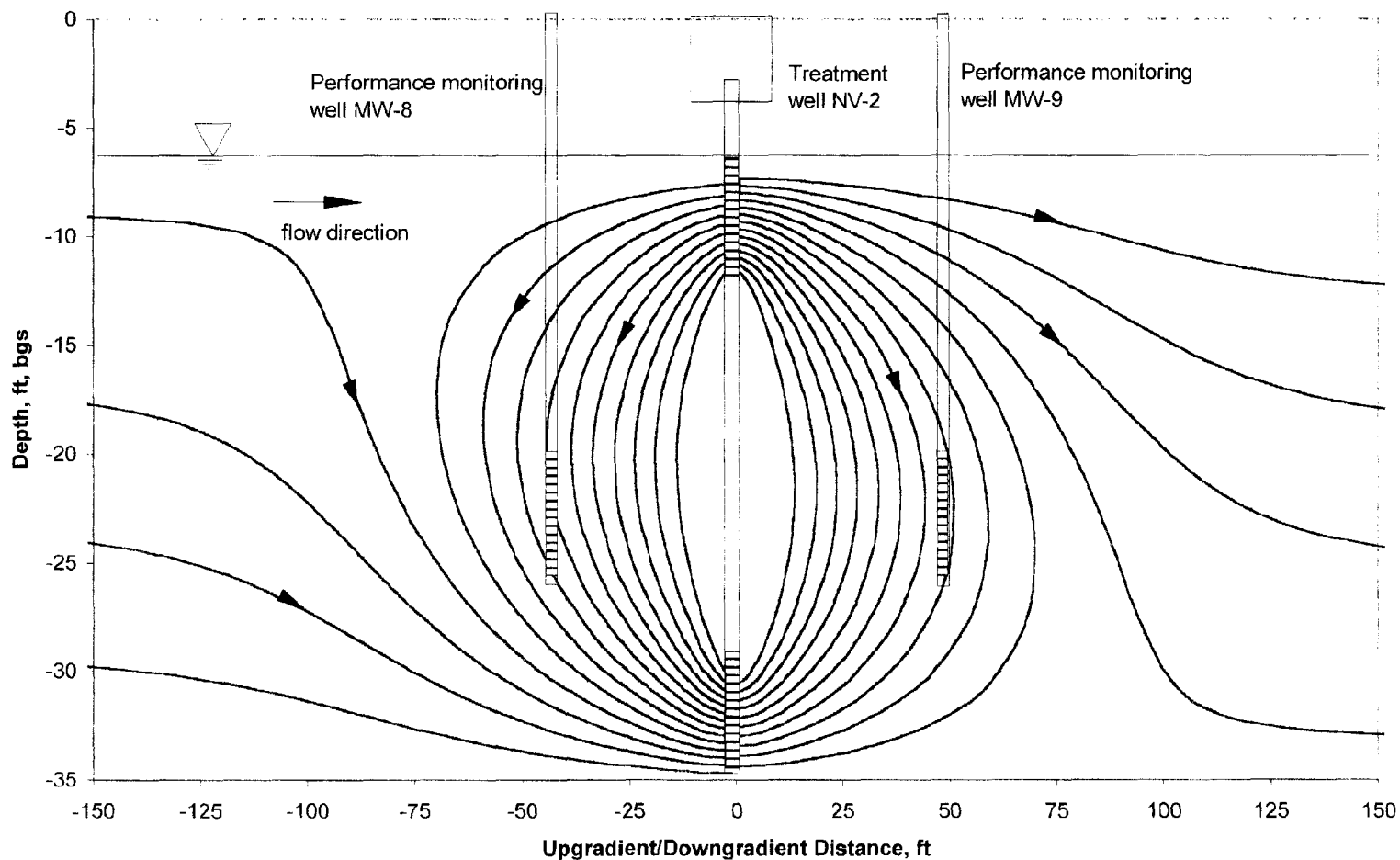
This figure shows the predicted flow patterns around the treatment wells. The treatment zone is 150 feet (diameter). Field monitoring data (concentration reduction in monitoring wells) have verified the treatment zone size

Figure 8-3 Recirculating Well Flow Paths Perpendicular to Gradient, Former EMF Site

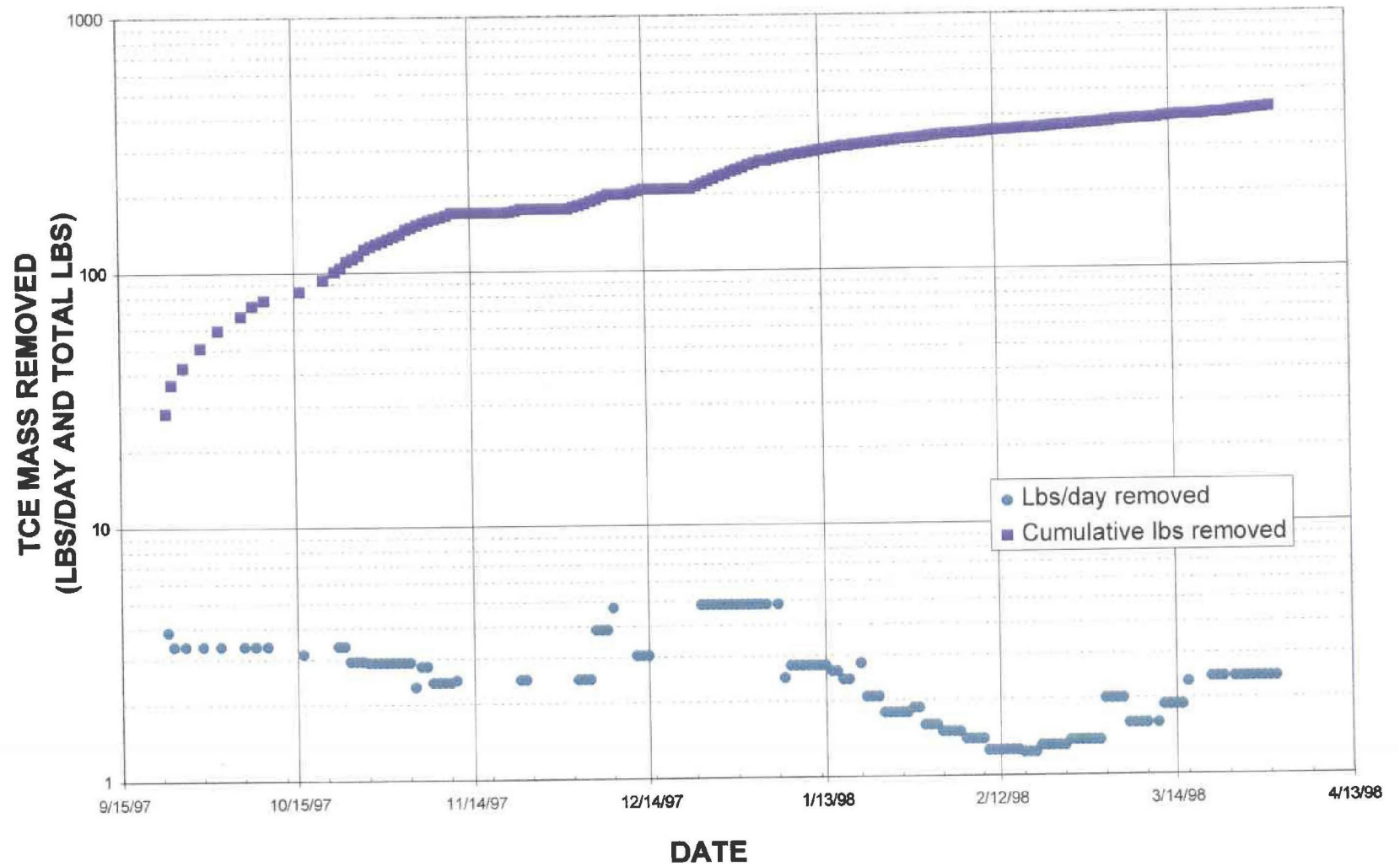


This figure shows the predicted flow patterns around the down gradient treatment well (NV-2, patterns which are parallel to the flow direction). See Figure 8-2 for concentration reductions in the performance monitoring wells shown in this figure.

**Figure 8-4 Recirculating Well Flow Paths Parallel to Gradient
Former EMF Site**



**FIGURE 8-5 IN-WELL STRIPPING SYSTEM TCE MASS REMOVAL,
FORMER EMF SITE**



9.0 References

EPA 1980a. Ambient Water Quality Criteria for Trichloroethene, EPA Office of Water, Criteria and Standards Division, EPA 440/5-80-077

EPA 1980b. Ambient Water Quality Criteria for Dichloroethene, EPA Office of Water, Criteria and Standards Division, EPA 440/5-80-041

EPA 1980c. Ambient Water Quality Criteria for Vinyl Chloride, EPA Office of Water, Criteria and Standards Division, EPA 440/5-80-078

EPA 1997. Draft Interim Final OSWER Monitored Natural Attenuation Policy, OSWER Directive 9200.4-17, (December 1997)

Howard, Phillip H. 1991, Handbook of Environmental Degradation Rates, Lewis Publishers Inc., Chelsea, Michigan.

Landau 1993. 1993 Groundwater Monitoring Former EMF Facility (May 18, 1993).

Weston 1997a. Remedial Investigation/Feasibility Study, Former Electrical Manufacturing Facility, King County International Airport (June 27, 1997).

Weston 1997b. Independent Remedial Action, Cleanup Action Plan, Former Electrical Manufacturing Facility, King County International Airport (April 17, 1997).

Weston 1997c. Remedial Action Report, Independent Remedial Action Program, Former Electrical Manufacturing Facility, King County International Airport (August 7, 1997).

**Appendix A: Site Maps
& Groundwater Data**

Appendix A:

Site Maps with Recent Groundwater Monitoring Results

BOEING

**ELECTRONICS MANUFACTURING FACILITY
GROUNDWATER CLEAN-UP**

Sampling thru February 1998

Trichloroethene

LEGEND



0 25 50 75

Approximate Scale in Feet
1" = 75'

Trichloroethene			
ug/l			
	7/17/97	10/10/97	2/10/98
EMF-MW-1S	6.9	15.2	40.6

- ⊕ MONITORING WELL LOCATION & DESIGNATION
- NV-01 TREATMENT WELL LOCATION & DESIGNATION

KING COUNTY POLICE

EMF-MW-7	19.9	2.9	5.5
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PERIMETER ROAD

EQUIPMENT
TRAILER

EMF-MW-6	39.2	38.2	10.7
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EMF-NV-01	870000 E	1007000 E	430000
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EMF-MW-8	4700 E	7030	<1.0
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EMF-NV-02	125	652	7500
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EMF-MW-3S	8.72	5.7	3.8
EMF-MW-3D	85.4	<1.00	1.2

EMF-MW-10	29100 E	8300	114
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EMF-MW-1S	5.9	15.2	40.6
EMF-MW-1D	1.7	29.9	84.5

EMF-MW-9	17.9	18900 E	720
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KING COUNTY ARRIVALS BUILDING

EMF-MW-4	2.3	<1.00	1.9
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EMF-MW-5	<1.00	1.7	<1.00
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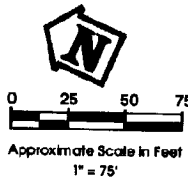
EMF-MW-2	<1.00	<1.00	<1.00
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KCSlip4 39564

SEA406094

BOEING
ELECTRONICS MANUFACTURING FACILITY
GROUNDWATER CLEAN-UP
 Sampling thru February 1998
 trans-1,2-Dichloroethene

LEGEND



trans-1,2-Dichloroethene			
ug/l	7/17/97	10/10/97	2/10/98
EMF-MW-1S	<1.00	<1.00	<1.00

- ⊕ MONITORING WELL LOCATION & DESIGNATION
- NV-01 TREATMENT WELL LOCATION & DESIGNATION

KING COUNTY POLICE

7	⊕	EMF-MW-7	<1.00	<1.00	<1.00
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PERIMETER ROAD

EQUIPMENT TRAILER

6	⊕	EMF-MW-6	<2.00	<1.00	<1.00
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EMF-NV-01	<2000	<5000	<10000
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EMF-MW-8	11.5	<200	21.9
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EMF-NV-02	40.6	42.3	15.3
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EMF-MW-3S	<1.00	<1.00	<1.00
EMF-MW-3D	<20	1.2	1.1

3D
3S

EMF-MW-1S	<1.00	<1.00	<1.00
EMF-MW-1D	<1.00	<1.00	2.4

1B 1D

EMF-MW-10	1.60	<100	<100
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10

9

EMF-MW-9	8.73	<100	<200
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FORMER 3-962 BLDG

KING COUNTY ARRIVALS BUILDING

4	⊕	EMF-MW-4	<2.00	<1.00	<1.00
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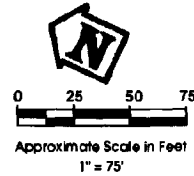
5	⊕	EMF-MW-5	<1.00	<1.00	<1.00
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2	⊕	EMF-MW-2	<1.00	<1.00	<1.00
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BOEING®
ELECTRONICS MANUFACTURING FACILITY
GROUNDWATER CLEAN-UP
 Sampling thru February 1998
 cis-1,2-Dichloroethene

KING COUNTY POLICE

LEGEND



cis-1,2-Dichloroethene ug/l			
	7/17/97	10/10/97	2/10/98
EMF-MW-1S	<1.00	1.6	6.6

- ⊕ MONITORING WELL LOCATION & DESIGNATION
- NV-01 TREATMENT WELL LOCATION & DESIGNATION

7	EMF-MW-7	<1.00	<1.00	<1.00
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PERIMETER ROAD

EQUIPMENT TRAILER

6	EMF-MW-6	<2.00	<1.00	<1.00
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EMF-NV-01	<2000	<5000	<10000
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EMF-MW-8	213	454	808
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EMF-NV-02	388	1030 E	6200
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FORMER 3-962 BLDG

EMF-MW-10	3086	432	3700
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EMF-MW-3S	<1.00	<1.00	<1.00
EMF-MW-3D	<20.00	19.1	13.4

EMF-MW-1S	<1.00	1.6	6.6
EMF-MW-1D	1.4	11	171 E

EMF-MW-9	116.2	1350	8250
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KING COUNTY ARRIVALS BUILDING

EMF-MW-4	<2.00	1.4	<1.00
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EMF-MW-5	2.8	3.2	5.3
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EMF-MW-2	3.7	2.4	2.3
----------	-----	-----	-----

BOEING®
ELECTRONICS MANUFACTURING FACILITY
GROUNDWATER CLEAN-UP
 Sampling thru February 1998
 Chlorides

LEGEND



0 25 50 75
 Approximate Scale in Feet
 1" = 75'

Chlorides mg/l	7/17/97	10/10/97	2/10/98
EMF-MW-1S	21	48	26

- ⊕ MONITORING WELL LOCATION & DESIGNATION
- NV-01 TREATMENT WELL LOCATION & DESIGNATION

KING COUNTY POLICE

7

⊕	EMF-MW-7	6.7	9.4	6.7
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PERIMETER ROAD

EQUIPMENT TRAILER

6

⊕	EMF-MW-6	4.9	5.8	6.3
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EMF-NV-01	6.8	9.7	9.3
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EMF-MW-8	5.5	17	33
----------	-----	----	----

EMF-NV-02	7	18	9.5
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EMF-MW-3S	3.9	5.1	2.9
EMF-MW-3D	6	5	48

3D
3S

EMF-MW-1S	21	48	26
EMF-MW-1D	20	25	14

1S 1D

10

⊕	EMF-MW-10	28	9.2	44
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EMF-MW-9	9.1	18	50
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KING COUNTY ARRIVALS BUILDING

4

⊕	EMF-MW-4	1.8	1.8	3.1
---	----------	-----	-----	-----

5

⊕	EMF-MW-5	5	5.6	7.1
---	----------	---	-----	-----

2

⊕	EMF-MW-2	3.4	2.5	4.1
---	----------	-----	-----	-----

FORMER 3-962 BLDG



**ELECTRONICS MANUFACTURING FACILITY
GROUNDWATER CLEAN-UP**

Sampling thru February 1998

Vinyl Chloride

LEGEND



0 25 50 75

Approximate Scale in Feet

1" = 75'

Vinyl Chloride			
ug/l	7/17/97	10/10/97	2/10/98
EMF-MW-1S	<1.00	<1.00	<1.00

● MONITORING WELL LOCATION & DESIGNATION

● NV-01 TREATMENT WELL LOCATION & DESIGNATION

KING COUNTY POLICE

7

EMF-MW-7	<1.00	<1.00	<1.00
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PERIMETER ROAD

EQUIPMENT
TRAILER

6

EMF-MW-6	<2.00	<1.00	<1.00
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EMF-NV-01	<2000	<5000	<10000
-----------	-------	-------	--------

NV-01

EMF-MW-8	<10	<200	430
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9

EMF-NV-02	<20	97.2	312
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NV-02

10

EMF-MW-10	322	<100	<100
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3D

38

EMF-MW-3S	<1.00	<1.00	<1.00
EMF-MW-3D	<20	45	41.3

18

1D

EMF-MW-1S	<1.00	<1.00	<1.00
EMF-MW-1D	<1.00	2.4	18.5

9

EMF-MW-9	12.74	<100	1120
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KING COUNTY ARRIVALS BUILDING

4

EMF-MW-4	<2.00	<1.00	<1.00
----------	-------	-------	-------

5

EMF-MW-5	1.7	1.2	1.4
----------	-----	-----	-----

2

EMF-MW-2	2.2	2.7	5.9
----------	-----	-----	-----

KCSlip4 39568

SEA406098

Appendix B:
Analytical Results

Appendix B:
Analytical Results from Recent Groundwater Sampling Events

Data from monitoring events in:

February 1998

October 1997

July 1997

**EMF QUARTERLY GROUNDWATER SAMPLING
FEBRUARY 1998**

EAL Sample ID:	35144	35145	35145	35151	35147	35146	35153	35152	35149
Sample Name:	EMF-MW-1S	EMF-MW-1D	EMF-MW-1D	EMF-MW-2	EMF-MW-3S	EMF-MW-3D	EMF-MW-4	EMF-MW-5	EMF-MW-6
Sample Date:	10-FEB-1998	10-FEB-1998	10-FEB-1998	11-FEB-1998	10-FEB-1998	10-FEB-1998	11-FEB-1998	11-FEB-1998	10-FEB-1998
Dilution factor	1	1	2	1	1	1	1	1	1
Test ID: VOA-60	Units								
Dichlorodifluoromethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Chloromethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Vinyl Chloride	ug/l	<1.00	18.5	14.7	5.9	<1.00	41.3	<1.00	1.4
Bromomethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Chloroethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Acrolein	ug/l	<5.00	<5.00	<10.00	<5.00	<5.00	<5.00	<5.00	<5.00
Trichlorofluoromethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Acetone (2-Propanone)	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	8.2	<1.00	<1.00
1,1-Dichloroethene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Acrylonitrile	ug/l	<5.00	<5.00	<10.00	<5.00	<5.00	<5.00	<5.00	<5.00
Methylene Chloride	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Carbon Disulfide	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
trans-1,2-Dichloroethene	ug/l	<1.00	2.4	2.1	<1.00	<1.00	1.1	<1.00	<1.00
1,1-Dichloroethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
2-Butanone (MEK)	ug/l	<4.00	<4.00	<8.00	<4.00	<4.00	<4.00	<4.00	<4.00
cis-1,2-Dichloroethene	ug/l	6.6	171.00 E	137	2.3	<1.00	13.4	<1.00	5.3
Bromochloromethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Chloroform	ug/l	<1.00	<1.00	<2.00	<1.00	1.3	<1.00	20	<1.00
2,2-Dichloropropane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2-Dichloroethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,1,1-Trichloroethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,1-Dichloropropene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Carbon Tetrachloride	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Benzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Dibromomethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2-Dichloropropane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Trichloroethene	ug/l	40.6	84.5	76.5	<1.00	3.8	1.2	1.9	<1.00
Bromodichloromethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
2-Chloroethylvinyl Ether	ug/l	<2.00	<2.00	<4.00	<2.00	<2.00	<2.00	<2.00	<2.00
cis-1,3-Dichloropropene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
y	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
trans-1,3-Dichloropropene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,1,2-Trichloroethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Toluene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00

EMF QUARTERLY GROUNDWATER SAMPLING
FEBRUARY 1998

EAL Sample ID:	35144	35145	35145	35151	35147	35146	35153	35152	35149
Sample Name:	EMF-MW-1S	EMF-MW-1D	EMF-MW-1D	EMF-MW-2	EMF-MW-3S	EMF-MW-3D	EMF-MW-4	EMF-MW-5	EMF-MW-6
Sample Date:	10-FEB-1998	10-FEB-1998	10-FEB-1998	11-FEB-1998	10-FEB-1998	10-FEB-1998	11-FEB-1998	11-FEB-1998	10-FEB-1998
Dilution factor	1	1	2	1	1	1	1	1	1
1,3-Dichloropropane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
2-Hexanone	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Dibromochloromethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2-Dibromoethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Tetrachloroethene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,1,1,2-Tetrachloroethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Chlorobenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Ethylbenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Bromoform	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Styrene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Xylene (Total)	ug/l	<2.00	<2.00	<4.00	<2.00	<2.00	<2.00	<2.00	<2.00
1,2,3-Trichloropropane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Isopropylbenzene (cumene)	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Bromobenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
n-Propylbenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
2-Chlorotoluene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
4-Chlorotoluene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,3,5-Trimethylbenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
tert-Butylbenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2,4-Trimethylbenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
sec-Butylbenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,3-Dichlorobenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,4-Dichlorobenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
4-Isopropyltoluene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2-Dichlorobenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
n-Butylbenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2-Dibromo-3-Chloropropane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2,4-Trichlorobenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Naphthalene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Hexachlorobutadiene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2,3-Trichlorobenzene	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,1,2,2-Tetrachloroethane	ug/l	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00
Dibromofluoromethane	% Rec	99.4	100.8	98.8	96.2	98.6	98.8	92.4	100.8
Toluene-d8	% Rec	104	102.6	98.2	100	105.4	103.4	104	103.8

EMF QUARTERLY GROUNDWATER SAMPLING
FEBRUARY 1998

EAL Sample ID:	35148	35143	35142	35141	35139	35140	35150	35154
Sample Name:	EMF-MW-7	EMF-MW-8	EMF-MW-9	EMF-MW-10	EMF-NV-01	EMF-NV-02	EMF-DUP	TRIP BLANK
Sample Date:	10-FEB-1998	10-FEB-1998	9-FEB-1998	9-FEB-1998	9-FEB-1998	9-FEB-1998	10-FEB-1998	11-FEB-1998
Dilution factor	1	10	200	100	10000	100	10	1
Test ID: VOA-60	Units							
Dichlorodifluoromethane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
Chloromethane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
Vinyl Chloride	ug/l	<1.00	430	1120	<100.00	<10000.00	312	423
Bromomethane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
Chloroethane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
Acrolein	ug/l	<5.00	<50.00	<1000.00	<500.00	<50000.00	<500.00	<50.00
Trichlorofluoromethane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
Acetone (2-Propanone)	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
1,1-Dichloroethene	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
Acrylonitrile	ug/l	<5.00	<50.00	<1000.00	<500.00	<50000.00	<500.00	<50.00
Methylene Chloride	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
Carbon Disulfide	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
trans-1,2-Dichloroethene	ug/l	<1.00	21.9	<200.00	<100.00	<10000.00	153	21.3
1,1-Dichloroethane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
2-Butanone (MEK)	ug/l	<4.00	<40.00	<800.00	<400.00	<40000.00	<400.00	<40.00
cis-1,2-Dichloroethene	ug/l	<1.00	808	8250	3700	<10000.00	6200	788
Bromochloromethane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
Chloroform	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
2,2-Dichloropropane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
1,2-Dichloroethane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
1,1,1-Trichloroethane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
1,1-Dichloropropene	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
Carbon Tetrachloride	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
Benzene	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
Dibromomethane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
1,2-Dichloropropane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
Trichloroethene	ug/l	5.6	<10.00	720	114	430000	7500	<10.00
Bromodichloromethane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
2-Chloroethylvinyl Ether	ug/l	<2.00	<20.00	<400.00	<200.00	<20000.00	<200.00	<20.00
cis-1,3-Dichloropropene	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
y	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
trans-1,3-Dichloropropene	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
1,1,2-Trichloroethane	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00
Toluene	ug/l	<1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00

EMF QUARTERLY GROUNDWATER SAMPLING
FEBRUARY 1998

EAL Sample ID:	35148	35143	35142	35141	35139	35140	35150	35154
Sample Name:	EMF-MW-7	EMF-MW-8	EMF-MW-9	EMF-MW-10	EMF-NV-01	EMF-NV-02	EMF-DUP	TRIP BLANK
Sample Date:	10-FEB-1998	10-FEB-1998	9-FEB-1998	9-FEB-1998	9-FEB-1998	9-FEB-1998	10-FEB-1998	11-FEB-1998
Dilution factor	1	10	200	100	10000	100	10	1
1,3-Dichloropropane	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
2-Hexanone	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
Dibromochloromethane	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
1,2-Dibromoethane	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
Tetrachloroethene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
1,1,1,2-Tetrachloroethane	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
Chlorobenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
Ethylbenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
Bromoform	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
Styrene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
Xylene (Total)	ug/l <2.00	<20.00	<400.00	<200.00	<20000.00	<200.00	<20.00	<2.00
1,2,3-Trichloropropane	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
Isopropylbenzene (cumene)	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
Bromobenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
n-Propylbenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
2-Chlorotoluene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
4-Chlorotoluene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
1,3,5-Trimethylbenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
tert-Butylbenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
1,2,4-Trimethylbenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
sec-Butylbenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
1,3-Dichlorobenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
1,4-Dichlorobenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
4-Isopropyltoluene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
1,2-Dichlorobenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
n-Butylbenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
1,2-Dibromo-3-Chloropropane	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
1,2,4-Trichlorobenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
Naphthalene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
Hexachlorobutadiene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
1,2,3-Trichlorobenzene	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
1,1,2,2-Tetrachloroethane	ug/l <1.00	<10.00	<200.00	<100.00	<10000.00	<100.00	<10.00	<1.00
Dibromofluoromethane	% Rec 100.8	96.4	99.4	101.4	105.6	101.6	96.4	94.8
Toluene-d8	% Rec 99.6	95.2	99	104.2	103.4	103	96.8	97.6

EMF QUARTERLY GROUNDWATER MONITORING
FEBRUARY 1998

EAL Sample ID:		35144	35145	35151	35147	35146	35153	35152	35149
Sample Name:		EMF-MW-1S	EMF-MW-1D	EMF-MW-2	EMF-MW-3S	EMF-MW-3D	EMF-MW-4	EMF-MW-5	EMF-MW-6
Sample Date:		10-FEB-1998	10-FEB-1998	11-FEB-1998	10-FEB-1998	10-FEB-1998	11-FEB-1998	11-FEB-1998	10-FEB-1998
Test ID: ANIONS-ARI									
Nitrate	mg/L	13	0.06	0.28	0.43	0.06	0.17	0.04	1.2
Nitrite	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sulfate	mg/L	220	210	9.4	44	10	5.8	80	61
Carbonate	mg/L	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Bicarbonate	mg/L	51	96	110	92	170	31	150	100
Chloride	mg/L	26	14	4.1	2.9	4.8	3.1	7.1	6.3
O-Phosphate	mg/L	<0.004	<0.004	0.058	0.029	0.004	0.014	0.45	0.042
Sulfide	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Test ID: GFAA									
Antimony	ug/L	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3
Arsenic	ug/L	4.9	2	<1.5	<1.5	<1.5	<1.5	1.9	<1.5
Cadmium	ug/L	0.19	<0.10	0.18	0.34	<0.10	0.1	<0.10	<0.10
Lead	ug/L	1.6	1.2	9	11	2.3	<1.030	<1.030	12
Selenium	ug/L	<1.530	<1.530	<1.530	<1.530	<1.530	<1.530	<1.530	<1.530
Thallium	ug/L	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5
Test ID: HG									
Mercury in aqueous solution	ug/l	<0.021	<0.021	<0.021	<0.021	<0.021	<0.021	<0.021	<0.021
Test ID: ICP-PP-D									
Silver	mg/L	<0.0030	<0.0030	<0.0030	<0.0030	<0.0030	<0.0030	<0.0030	<0.0030
Beryllium	mg/L	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Cadmium	mg/L	<0.0040	<0.0040	<0.0040	0.009	<0.0040	<0.0040	<0.0040	0.009
Chromium	mg/L	<0.0060	<0.0060	<0.0060	<0.0060	<0.0060	<0.0060	<0.0060	<0.0060
Copper	mg/L	0.031	0.018	0.054	0.019	0.016	0.024	0.029	0.04
Iron	mg/L	15	17	22	1.8	14	3.7	14	2.9
Manganese	mg/L	0.39	0.64	0.25	0.19	0.55	0.047	0.67	0.022
Nickel	mg/L	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031
Zinc	mg/L	<0.018	<0.018	<0.018	0.022	<0.018	<0.018	<0.018	<0.018

EMF QUARTERLY GROUNDWATER MONITORING
FEBRUARY 1998

EAL Sample ID:		35148	35143	35142	35141	35139	35140	35150
Sample Name:		EMF-MW-7	EMF-MW-8	EMF-MW-9	EMF-MW-10	EMF-NV-01	EMF-NV-02	EMF-DUP
Sample Date:		10-FEB-1998	10-FEB-1998	9-FEB-1998	9-FEB-1998	9-FEB-1998	9-FEB-1998	10-FEB-1998
Test ID: ANIONS-ARI								
Nitrate	mg/L	0.76	0.05	0.02	<0.01	0.04	0.01	0.05
Nitrite	mg/L	<0.01	<0.01	0.02	<0.01	<0.01	0.02	<0.01
Sulfate	mg/L	65	<50.00	8.3	15	71	90	6.2
Carbonate	mg/L	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Bicarbonate	mg/L	93	210	190	180	110	71	200
Chloride	mg/L	6.7	33	50	44	9.3	9.5	32
O-Phosphate	mg/L	0.014	<0.004	<0.004	<0.004	<0.004	0.012	<0.004
Sulfide	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Test ID: GFAA								
Antimony	ug/L	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3
Arsenic	ug/L	<1.5	<1.5	<1.5	2.8	<1.5	4.3	<1.5
Cadmium	ug/L	<0.10	<0.10	<0.10	<0.10	0.47	<0.10	<0.10
Lead	ug/L	11	1.3	<1.030	6.9	1.2	1.1	1.6
Selenium	ug/L	<1.530	<1.530	<1.530	<1.530	<1.530	<1.530	<1.530
Thallium	ug/L	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5
Test ID: HG								
Mercury in aqueous solution	ug/l	<0.021	<0.021	<0.021	<0.021	<0.021	<0.021	<0.021
Test ID: ICP-PP-D								
Silver	mg/L	<0.0030	<0.0030	<0.0030	<0.0030	0.006	<0.0030	<0.0030
Beryllium	mg/L	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Cadmium	mg/L	0.005	<0.0040	<0.0040	<0.0040	0.007	0.004	<0.0040
Chromium	mg/L	<0.0060	<0.0060	<0.0060	0.095	0.01	<0.0060	<0.0060
Copper	mg/L	0.065	0.003	<0.0030	0.24	0.02	0.024	0.04
Iron	mg/L	3	19	43	6.9	5.3	30	20
Manganese	mg/L	0.13	0.37	0.62	0.11	0.13	0.3	0.39
Nickel	mg/L	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031
Zinc	mg/L	0.035	<0.018	<0.018	<0.018	0.042	<0.018	0.018

EMF QUARTERLY GROUNDWATER SAMPLING
OCTOBER 1997

EAL Sample ID:	32699	32700	32715	32701	32702	32703	32704	32705
Sample Name:	GW02-EMF01S-0	GW02-EMF01D-0	GW02-EMF02-0	GW02-EMF03S-0	GW02-EMF03D-0	GW02-EMF04-0	GW02-EMF05-0	GW02-EMF06-0
Sample Date:	10-Oct-97	10-Oct-97	9-Oct-97	10-Oct-97	10-Oct-97	9-Oct-97	9-Oct-97	9-Oct-97
Dilution factor	1	1	1	1	1	1	1	1
Test ID: VOA-60	Units							
Dichlorodifluoromethane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Chloromethane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Vinyl Chloride	ug/l	<1.00	2.4	2.7	<1.00	4.5	<1.00	1.2
Bromomethane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Chloroethane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Trichlorofluoromethane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Acetone (2-Propanone)	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,1-Dichloroethene	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Methylene Chloride	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Carbon Disulfide	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
trans-1,2-Dichloroethene	ug/l	<1.00	<1.00	<1.00	<1.00	1.2	<1.00	<1.00
1,1-Dichloroethane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
2-Butanone (MEK)	ug/l	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00
cis-1,2-Dichloroethene	ug/l	1.6	11	2.4	<1.00	19.1	1.4	3.2
Bromochloromethane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Chloroform	ug/l	<1.00	<1.00	<1.00	1.4	<1.00	<1.00	<1.00
2,2-Dichloropropane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2-Dichloroethane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,1,1-Trichloroethane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,1-Dichloropropene	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Carbon Tetrachloride	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Benzene	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Dibromomethane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2-Dichloropropane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Trichloroethene	ug/l	15.2	29.9	<1.00	5.7	<1.00	<1.00	1.7
Bromodichloromethane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
2-Chloroethylvinyl Ether	ug/l	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00
cis-1,3-Dichloropropene	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
4-Methyl-2-Pentanone (MIF)	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
trans-1,3-Dichloropropene	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,1,2-Trichloroethane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Toluene	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,3-Dichloropropane	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
2-Hexanone	ug/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00

EMF QUARTERLY GROUNDWATER SAMPLING
OCTOBER 1997

EAL Sample ID:	32699	32700	32715	32701	32702	32703	32704	32705
Sample Name:	GW02-EMF01S-0	GW02-EMF01D-0	GW02-EMF02-0	GW02-EMF03S-0	GW02-EMF03D-0	GW02-EMF04-0	GW02-EMF05-0	GW02-EMF06-0
Sample Date:	10-Oct-97	10-Oct-97	9-Oct-97	10-Oct-97	10-Oct-97	9-Oct-97	9-Oct-97	9-Oct-97
Dilution factor	1	1	1	1	1	1	1	1
Dibromochloromethane	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2-Dibromoethane	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Tetrachloroethene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,1,1,2-Tetrachloroethane	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Chlorobenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Ethylbenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Bromoform	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Styrene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Xylene (Total)	ug/l <2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00
1,2,3-Trichloropropane	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Isopropylbenzene (Cumene)	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Bromobenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
n-Propylbenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
2-Chlorotoluene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
4-Chlorotoluene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,3,5-Trimethylbenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
tert-Butylbenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2,4-Trimethylbenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
sec-Butylbenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,3-Dichlorobenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,4-Dichlorobenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
4-Isopropyltoluene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2-Dichlorobenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
n-Butylbenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2-Dibromo-3-Chloropropane	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2,4-Trichlorobenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Naphthalene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Hexachlorobutadiene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,2,3-Trichlorobenzene	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
1,1,2,2-Tetrachloroethane	ug/l <1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Dibromofluoromethane	% Rec 94	93.6	94.4	92.4	91.6	94.2	92.6	94.8
Toluene-d8	% Rec 102.6	103.4	98.4	94.2	101.4	100.4	101.4	103.6
4-Bromofluorobenzene	% Rec 92	92.2	98.8	96	93.4	91.2	90.2	97.2

EMF QUARTERLY GROUNDWATER SAMPLING
OCTOBER 1997

EAL Sample ID:	32706	32707	32708	32709	32710	32711	32712	32714
Sample Name:	GW02-EMF07-0	GW02-EMF08-0	GW02-EMF09-0	GW02-EMF10-0	GW02-EMFNOVOC01	GW02-EMFNOVOC02	TRIP BLANK	TRIP BLANK
Sample Date:	10-Oct-97	9-Oct-97	9-Oct-97	9-Oct-97	10-Oct-97	9-Oct-97	9-Oct-97	10-Oct-97
Dilution factor	1	200	100	100	5000	5	1	1
Test ID: VOA-60	Units							
Dichlorodifluoromethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
Chloromethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
Vinyl Chloride	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	97.2	<1.00
Bromomethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
Chloroethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
Trichlorofluoromethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
Acetone (2-Propanone)	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
1,1-Dichloroethene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
Methylene Chloride	ug/l	<1.00	236	<100.00	<100.00	<5000.00	8.2	<1.00
Carbon Disulfide	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
trans-1,2-Dichloroethene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	42.3	<1.00
1,1-Dichloroethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
2-Butanone (MEK)	ug/l	<4.00	<800.00	<400.00	<400.00	<20000.00	<20.00	<4.00
cis-1,2-Dichloroethene	ug/l	<1.00	454	1350	432	<5000.00	1030.00 E	<1.00
Bromochloromethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
Chloroform	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
2,2-Dichloropropane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
1,2-Dichloroethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
1,1,1-Trichloroethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
1,1-Dichloropropene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
Carbon Tetrachloride	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
Benzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
Dibromomethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
1,2-Dichloropropane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
Trichloroethene	ug/l	2.9	7030	18900.00 E	8300	1007000 E	652	<1.00
Bromodichloromethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
2-Chloroethylvinyl Ether	ug/l	<2.00	<400.00	<200.00	<200.00	<10000.00	<10.00	<2.00
cis-1,3-Dichloropropene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
4-Methyl-2-Pentanone (MIE)	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
trans-1,3-Dichloropropene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
1,1,2-Trichloroethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
Toluene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
1,3-Dichloropropane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00
2-Hexanone	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00

EMF QUARTERLY GROUNDWATER SAMPLING
OCTOBER 1997

EAL Sample ID		32706	32707	32708	32709	32710	32711	32712	32714
Sample Name		GW02-EMF07-0	GW02-EMF08-0	GW02-EMF09-0	GW02-EMF10-0	GW02-EMFNOVOC01	GW02-EMFNOVOC02	TRIP BLANK	TRIP BLANK
Sample Date		10-Oct-97	9-Oct-97	9-Oct-97	9-Oct-97	10-Oct-97	9-Oct-97	9-Oct-97	10-Oct-97
Dilution factor		1	200	100	100	5000	5	1	1
Dibromochloromethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
1,2-Dibromomethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
Tetrachloroethene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
1,1,1,2-Tetrachloroethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
Chlorobenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
Ethylbenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
Bromoform	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
Styrene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
Xylene (Total)	ug/l	<2.00	<400.00	<200.00	<200.00	<10000.00	<10.00	<2.00	<2.00
1,2,3-Trichloropropane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
Isopropylbenzene (cumene)	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
Bromobenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
n-Propylbenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
2-Chlorotoluene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
4-Chlorotoluene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
1,3,5-Trimethylbenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
tert-Butylbenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
1,2,4-Trimethylbenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
sec-Butylbenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
1,3-Dichlorobenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
1,4-Dichlorobenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
4-Isopropyltoluene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
1,2-Dichlorobenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
n-Butylbenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
1,2-Dibromo-3-Chloropropane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
1,2,4-Trichlorobenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
Naphthalene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
Hexachlorobutadiene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
1,2,3-Trichlorobenzene	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
1,1,2,2-Tetrachloroethane	ug/l	<1.00	<200.00	<100.00	<100.00	<5000.00	<5.00	<1.00	<1.00
Dibromofluoromethane	% Rec	94.4	92.4	95	92.4	92.8	92.6	95	94.2
Toluene-d8	% Rec	100.2	100.4	102.6	103.4	98.8	99.8	103.6	101.2
4-Bromofluorobenzene	% Rec	95.8	92.8	99.6	97.2	88.6	91.2	96	97

EMF QUARTERLY GROUNDWATER MONITORING
OCTOBER 1997

EAL Sample ID:	32699	32700	32715	32701	32702	32703	32704	32705
Sample Name:	GW02-EMF01S-0	GW02-EMF01D-0	GW02-EMF02-0	GW02-EMF03S-0	GW02-EMF03D-0	GW02-EMF04-0	GW02-EMF05-0	GW02-EMF06-C
Sample Date:	10-Oct-97	10-Oct-97	9-Oct-97	10-Oct-97	10-Oct-97	9-Oct-97	9-Oct-97	9-Oct-97
Test ID: ANIONS-ARI								
Nitrate	mg/L	9.8	0.03	1	1.3	0.02	0.55	2.2
Nitrite	mg/L	0.12	<0.01	<0.01	0.02	<0.01	<0.01	<0.01
Sulfate	mg/L	250	370	9.6	31	16	86	36
Carbonate	mg/L	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Bicarbonate	mg/L	22	22	96	67	130	92	60
Chloride	mg/L	48	25	2.5	5.1	5	1.8	5.8
O-Phosphate	mg/L	<0.00	<0.004	0.38	<0.004	<0.004	0.027	<0.004
Sulfide	mg/L	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Test ID: GFAA								
Antimony	ug/L	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3
Arsenic	ug/L	<1.5	1.8	<1.5	<1.5	<1.5	5.6	<1.5
Cadmium	ug/L	<0.10	<0.10	0.58	<0.10	<0.10	<0.10	<0.10
Lead	ug/L	1.2	0.5	2.8	1.1	0.8	0.88	0.63
Selenium	ug/L	<1.530	<1.530	<1.530	<1.530	<1.530	<1.530	<1.530
Thallium	ug/L	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5
Test ID: HG								
Mercury in aqueous solution	ug/l	0.065	0.061	0.11	0.062	0.076	0.069	0.079
Test ID: ICP-PP-D								
Silver	mg/L	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Beryllium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	mg/L	0.029	0.031	0.01	0.004	0.01	0.006	0.004
Chromium	mg/L	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Copper	mg/L	0.053	0.037	0.046	0.017	0.022	0.035	0.003
Iron	mg/L	4.1	29	3.6	0.009	12	0.021	26
Manganese	mg/L	0.3	1.1	0.23	0.005	0.51	0.001	0.67
Nickel	mg/L	<0.0080	<0.0080	<0.0080	<0.0080	<0.0080	<0.0080	<0.0080
Zinc	mg/L	0.011	0.04	370	0.14	0.13	0.035	0.017
Test ID: TDS								
Total dissolved solids	mg/L	616	706	900	152	185	135	293
Test ID: TOC-ARI								
TOC	mg/L	2.3	2.6	<1.5	<1.5	2.9	<1.5	3.5

EMF QUARTERLY GROUNDWATER MONITORING
OCTOBER 1997

EAL Sample ID:		32706	32707	32708	32709	32710	32711	32712	32714
Sample Name:		GW02-EMF07-0	GW02-EMF08-0	GW02-EMF09-0	GW02-EMF10-0	GW02-EMFNOVOC01	GW02-EMFNOVOC02	TRIP BLANK	TRIP BLANK
Sample Date:		10-Oct-97	9-Oct-97	9-Oct-97	9-Oct-97	10-Oct-97	9-Oct-97	9-Oct-97	10-Oct-97
Test ID: ANIONS-ARI									
Nitrate	mg/L	3.1	<0.01	<0.01	0.03	<0.01	<0.01	NA	NA
Nitrite	mg/L	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	NA	NA
Sulfate	mg/L	53	100	120	70	67	99	NA	NA
Carbonate	mg/L	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	NA	NA
Bicarbonate	mg/L	110	72	52	58	89	84	NA	NA
Chloride	mg/L	9.4	17	18	9.2	9.7	18	NA	NA
O-Phosphate	mg/L	0.015	<0.004	<0.004	0.022	0.012	<0.004	NA	NA
Sulfide	mg/L	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	NA	NA
Test ID: GFAA									
Antimony	ug/L	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	NA	NA
Arsenic	ug/L	<1.5	<1.5	<1.5	1.6	<1.5	2.3	NA	NA
Cadmium	ug/L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	NA	NA
Lead	ug/L	0.45	0.38	0.4	0.6	0.38	0.43	NA	NA
Selenium	ug/L	<1.530	<1.530	<1.530	<1.530	<1.530	<1.530	NA	NA
Thallium	ug/L	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	NA	NA
Test ID: HG									
Mercury in aqueous solution	ug/l	0.093	0.1	0.1	0.11	0.1	0.11	NA	NA
Test ID: ICP-PP-D									
Silver	mg/L	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	NA	NA
Beryllium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	NA	NA
Cadmium	mg/L	0.006	0.013	0.009	0.007	0.009	0.01	NA	NA
Chromium	mg/L	<0.0020	0.002	<0.0020	0.004	0.004	<0.0020	NA	NA
Copper	mg/L	0.011	0.021	0.005	0.014	0.02	0.007	NA	NA
Iron	mg/L	0.033	14	20	1.1	3.5	1	NA	NA
Manganese	mg/L	0.023	0.3	0.31	0.05	0.13	0.24	NA	NA
Nickel	mg/L	<0.0080	<0.0080	<0.0080	<0.0080	<0.0080	0.019	NA	NA
Zinc	mg/L	0.043	0.023	0.006	0.012	0.13	0.16	NA	NA
Test ID: TDS									
Total dissolved solids	mg/L	10219	301	293	233	253	250	NA	NA
Test ID: TOC-ARI									
TOC	mg/L	<1.5	<1.5	2.1	2.2	11	1.6	NA	NA

EMF QUARTERLY GROUNDWATER MONITORING
JULY 1997

EAL Sample ID:	30890	30885	30884	30831	30832	30828	30886	30827
Sample Name:	GW01-EMF01S-0	GW01-EMF01D-0	GW01-EMF02-0	GW01-EMF03S-0	GW01-EMF03D-0	GW01-EMF04-0	GW01-EMF05-0	GW01-EMF06-0
Sample Date:	18-Jul-97	18-Jul-97	18-Jul-97	17-Jul-97	17-Jul-97	18-Jul-97	18-Jul-97	17-Jul-97
Dilution factor	1	1	1	1	20	2	1	2
Test ID: VOA-60								
Dichlorodifluoromethane	ug/l	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
Chloromethane	ug/l	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
Vinyl Chloride	ug/l	<1.00	<1.00	2.2	<1.00	<20.00	<2.00	1.7
Bromomethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
Chloroethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
Trichlorofluoromethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
Acetone (2-Propanone)	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
1,1-Dichloroethene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
Methylene Chloride	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
Carbon Disulfide	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
trans-1,2-Dichloroethene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
1,1-Dichloroethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
2-Butanone (MEK)	ug/l	<4.00	<4.00	<4.00	<4.00	<80.00	<8.00	<4.00
cis-1,2-Dichloroethene	ug/l	<1.00	1.4	3.7	<1.00	<20.00	<2.00	2.8
Bromochloromethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
Chloroform	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
2,2-Dichloropropane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
1,2-Dichloroethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
1,1,1-Trichloroethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
1,1-Dichloropropene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
Carbon Tetrachloride	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
Benzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
Dibromomethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
1,2-Dichloropropane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
Trichloroethene	ug/l	6.9	1.7	<1.00	8.72	85.4	2.3	<1.00
Bromodichloromethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
2-Chloroethylvinyl Ether	ug/l	<2.00	<2.00	<2.00	<2.00	<40.00	<4.00	<2.00
cis-1,3-Dichloropropene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
4-Methyl-2-Pentanone (M	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
trans-1,3-Dichloropropene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
1,1,2-Trichloroethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
Toluene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
1,3-Dichloropropane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00
2-Hexanone	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00

EMF QUARTERLY GROUNDWATER MONITORING
JULY 1997

EAL Sample ID:		30890	30885	30884	30831	30832	30828	30886	30827
Sample Name:		GW01-EMF01S-0	GW01-EMF01D-0	GW01-EMF02-0	GW01-EMF03S-0	GW01-EMF03D-0	GW01-EMF04-0	GW01-EMF05-0	GW01-EMF06-0
Sample Date:		18-Jul-97	18-Jul-97	18-Jul-97	17-Jul-97	17-Jul-97	18-Jul-97	18-Jul-97	17-Jul-97
Dilution Factor:		1	1	1	1	20	2	1	2
Dibromofluoromethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
1,2-Dibromochloroethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
Tetrachloroethene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
1,1,1,2-Tetrachloroethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
Chlorobenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
Ethylbenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
Bromofluorobenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
Styrene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
Xylene (Total)	ug/l	<2.00	<2.00	<2.00	<2.00	<40.00	<4.00	<2.00	<4.00
1,2,3-Trichloropropane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
Isopropylbenzene (cumene)	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
Bromobenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
n-Propylbenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
2-Chlorotoluene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
4-Chlorotoluene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
1,3,5-Trimethylbenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
tert-Butylbenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
1,2,4-Trimethylbenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
sec-Butylbenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
1,3-Dichlorobenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
1,4-Dichlorobenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
4-Isopropyltoluene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
1,2-Dichlorobenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
n-Butylbenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
1,2-Dibromo-3-Chloropropane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
1,2,4-Trichlorobenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
Naphthalene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
Hexachlorobutadiene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
1,2,3-Trichlorobenzene	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
1,1,2,2-Tetrachloroethane	ug/l	<1.00	<1.00	<1.00	<1.00	<20.00	<2.00	<1.00	<2.00
Dibromofluoromethane	% Rec	100.2	102.8	101.8	107.4	94.2	93.46	97.6	95.4
Toluene-d8	% Rec	115.6	111	113.2	107.4	103.2	106.4	111.8	103.6
4-Bromofluorobenzene	% Rec	101.4	100.8	98.8	112.28	91.2	88.84	91.6	91.2

EMF QUARTERLY GROUNDWATER MONITORING
JULY 1997

EAL Sample ID:	30888	30830	30829	30826	30887	30889	30833	
Sample Name:	GW01-EMF07-0	GW01-EMF08-0	GW01-EMF09-0	GW01-EMF10-0	GW01-EMFNOVOC01	GW01-EMFNOVOC02	TRIP BLANK	
Sample Date:	18-Jul-97	17-Jul-97	17-Jul-97	17-Jul-97	18-Jul-97	18-JUL-1997	16-Jul-97	
Dilution Factor	1	10	2	100	2000	20	1	
Test ID: DA-60								
Dichlorodifluoromethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Chloromethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Vinyl Chloride	ug/l	<1.00	<10.00	12.74	322	<2000.00	<20.00	<1.00
Bromomethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Chloroethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Trichlorofluoromethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Acetone (2-Propanone)	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,1-Dichloroethene	ug/l	<1.00	11.2	<2.00	174	<2000.00	<20.00	<1.00
Methylene Chloride	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Carbon Disulfide	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
trans-1,2-Dichloroethene	ug/l	<1.00	11.5	8.73	160	<2000.00	40.6	<1.00
1,1-Dichloroethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
2-Butanone (MEK)	ug/l	<4.00	<40.00	<8.00	<400.00	<8000.00	<80.00	<4.00
cis-1,2-Dichloroethene	ug/l	<1.00	213	116.2	3086	<2000.00	388	<1.00
Bromochloromethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Chloroform	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
2,2-Dichloropropane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,2-Dichloroethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,1,1-Trichloroethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,1-Dichloropropene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Carbon Tetrachloride	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Benzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Dibromomethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,2-Dichloropropane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Trichloroethene	ug/l	19.9	4700.00 E	17.9	29100.00 E	870000.0 E	129	2
Bromodichloromethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
2-Chloroethylvinyl Ether	ug/l	<2.00	<20.00	<4.00	<200.00	<4000.00	<40.00	<2.00
cis-1,3-Dichloropropene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
4-Methyl-2-Pentanone (M)	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
trans-1,3-Dichloropropene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,1,2-Trichloroethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Toluene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,3-Dichloropropane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
2-Hexanone	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00

EMF QUARTERLY GROUNDWATER MONITORING
JULY 1997

EAL Sample ID:	30888	30830	30829	30826	30887	30889	30833	
Sample Name:	GW01-EMF07-0	GW01-EMF08-0	GW01-EMF09-0	GW01-EMF10-0	GW01-EMFNOVOC01	GW01-EMFNOVOC02	TRIP BLANK	
Sample Date:	18-Jul-97	17-Jul-97	17-Jul-97	17-Jul-97	18-Jul-97	18-JUL-1997	16-Jul-97	
Dilution Factor	1	10	2	100	2000	20	1	
Dibromochloromethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,2-Dibromoethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Tetrachloroethene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,1,1,2-Tetrachloroethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Chlorobenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Ethylbenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Bromobenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Styrene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Xylene (Total)	ug/l	<2.00	<20.00	<4.00	<200.00	<4000.00	<40.00	<2.00
1,2,3-Trichloropropane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Isopropylbenzene (cumene)	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Bromobenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
n-Propylbenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
2-Chlorotoluene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
4-Chlorotoluene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,3,5-Trimethylbenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
tert-Butylbenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,2,4-Trimethylbenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
sec-Butylbenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,3-Dichlorobenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,4-Dichlorobenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
4-Isopropyltoluene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,2-Dichlorobenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
n-Butylbenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,2-Dibromo-3-Chloropropane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,2,4-Trichlorobenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Naphthalene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Hexachlorobutadiene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,2,3-Trichlorobenzene	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
1,1,2,2-Tetrachloroethane	ug/l	<1.00	<10.00	<2.00	<100.00	<2000.00	<20.00	<1.00
Dibromofluoromethane	% Rec	100	95.8	94	94.8	101.4	100.4	118
Toluene-d8	% Rec	111.6	103.2	105	99.8	118.8	122.2	110.4
4-Bromofluorobenzene	% Rec	99	93	90.2	90.6	100.6	103.8	116.6

EMF QUARTERLY GROUNDWATER MONITORING
JULY 1997

EAL Sample ID:		30890	30885	30884	30831	30832	30828	30886	30827
Sample Name:		GW01-EMF01S-0	GW01-EMF01D-0	GW01-EMF02-0	GW01-EMF03S-0	GW01-EMF03D-0	GW01-EMF04-0	GW01-EMF05-0	GW01-EMF06-0
Sample Date:		18-JUL-1997	18-JUL-1997	18-JUL-1997	17-JUL-1997	17-JUL-1997	18-JUL-1997	18-JUL-1997	17-JUL-1997
ANION ANALYSIS									
Nitrate	mg/L	4.5	<0.01	0.23	0.5	0.14	0.64	0.02	0.39
Nitrite	mg/L	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
Sulfate	mg/L	300	420	30	20	12	14	100	44
Carbonate	mg/L	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Bicarbonate	mg/L	33	39	84	45	140	46	100	65
Chloride	mg/L	21	20	3.4	3.9	6	1.8	5	4.9
O-Phosphate	mg/L	<0.01	<0.01	0.04	0.04	<0.01	0.02	<0.01	0.04
Sulfide	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
CATION ANALYSIS									
Antimony	ug/L	<1.3	<1.3	<1.3	1.7	<1.3	<1.3	<1.3	<1.3
Arsenic	ug/L	<1.5	2	<1.5	<1.5	<1.5	<1.5	3.4	<1.5
Cadmium	ug/L	0.21	<0.10	<0.10	0.1	<0.10	<0.10	<0.10	<0.10
Lead	ug/L	0.48	0.35	0.8	0.75	0.85	0.85	0.7	0.7
Selenium	ug/L	<1.530	<1.530	<1.530	<1.530	<1.530	<1.530	<1.530	<1.530
Thallium	ug/L	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5
Mercury in aqueous solution									
Mercury in aqueous solution	ug/l	0.035	0.034	0.031	0.025	0.029	0.024	0.46	<0.021
Trace Elements									
Silver	mg/L	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Beryllium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	mg/L	0.024	0.024	0.008	0.003	0.008	0.003	0.014	0.003
Chromium	mg/L	0.002	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Copper	mg/L	0.003	<0.0010	0.001	0.013	<0.0010	0.002	<0.0010	0.002
Iron	mg/L	8.3	33	3	0.01	14	0.13	18	0.015
Manganese	mg/L	0.51	1.2	0.26	0.01	0.56	0.012	0.69	0.008
Nickel	mg/L	<0.0080	<0.0080	<0.0080	<0.0080	<0.0080	<0.0080	<0.0080	<0.0080
Zinc	mg/L	0.017	0.006	0.005	<0.0050	<0.0050	<0.0050	0.018	0.005
Dissolved Solids									
Total dissolved solids	mg/L	555	660	175	103	246	102	287	211
Organic Carbon									
TOC	mg/L	2.9	1.9	1.7	<1.5	3.9	<1.5	2.6	<1.5

EMF QUARTERLY GROUNDWATER MONITORING
JULY 1997

EAL Sample ID:		30888	30830	30829	30826	30887	30889	30833
Sample Name:		GW01-EMF07-0	GW01-EMF08-0	GW01-EMF09-0	GW01-EMF10-0	GW01-EMFNOVOC01	GW01-EMFNOVOC02	TRIP BLANK
Sample Date:		18-JUL-1997	17-JUL-1997	17-JUL-1997	17-JUL-1997	18-JUL-1997	18-JUL-1997	16-JUL-1997
Nitrate	mg/L	0.52	0.23	0.18	0.07	0.07	0.24	NA
Nitrite	mg/L	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	NA
Sulfate	mg/L	120	60	130	380	52	72	NA
Carbonate	mg/L	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	NA
Bicarbonate	mg/L	120	64	76	44	330	82	NA
Chloride	mg/L	6.7	5.5	9.1	28	6.8	7	NA
O-Phosphate	mg/L	0.03	<0.01	<0.01	0.01	<0.01	<0.01	NA
Sulfide	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NA
Antimony	ug/L	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	NA
Arsenic	ug/L	<1.5	<1.5	<1.5	<1.5	1.5	1.7	NA
Cadmium	ug/L	<0.10	<0.10	<0.10	0.3	<0.10	<0.10	NA
Lead	ug/L	0.75	1.4	0.93	0.85	0.43	0.65	NA
Selenium	ug/L	<1.530	<1.530	<1.530	<1.530	<1.530	<1.530	NA
Thallium	ug/L	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	NA
Mercury in aqueous solution	ug/l	0.036	<0.021	0.027	<0.021	0.041	0.039	NA
Silver	mg/L	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	NA
Beryllium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	NA
Cadmium	mg/L	0.006	0.003	0.01	0.011	0.004	0.007	NA
Chromium	mg/L	<0.0020	0.003	<0.0020	<0.0020	0.005	<0.0020	NA
Copper	mg/L	0.002	0.015	0.003	0.007	<0.0010	<0.0010	NA
Iron	mg/L	0.006	0.38	13	17	1.5	13	NA
Manganese	mg/L	0.001	0.083	0.39	0.64	0.11	0.2	NA
Nickel	mg/L	<0.0080	<0.0080	<0.0080	<0.0080	<0.0080	<0.0080	NA
Zinc	mg/L	0.025	0.011	<0.0050	0.006	3	0.006	NA
Total dissolved solids	mg/L	264	209	331	889	232	244	NA
TOC	mg/L	3.1	<1.5	2.6	3	49	2.2	NA

Appendix C: In-Well Stripping Technology

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Appendix C: Background Information on In-Well Stripping Technology

- 1) List of regulatory agency contacts who are familiar with the installation and performance of in-well stripping technology
- 2) Reprint of paper from "In Situ Remediation of the Geoenvironment", Geotechnical Publication No. 71, American Society of Civil Engineers. Reston, VA 1997
- 3) Summary performance data from in-well stripping systems installed throughout the US

References to regulatory agency personnel familiar with installation and performance of in-well stripping technology

Name/Agency	Phone number	Specific site where agency has provided oversight
Guy Gregory Ecology, Spokane Regional Office	(509) 456-6387	Pasco landfill CERCLA site, WA, performance data enclosed in data package
Brian Painter North Idaho Regional Office IDEQ	(208) 769-1422	Deming Industries site in Coeur d'Alene ID performance data enclosed in data package
Len Pinaud Massachusetts Dept. Of Environmental Protection	(508) 946-2871	Massachusetts Military Reservation, MA performance data enclosed in data package
Dr. Jack Hwang EPA Region 3, RCRA Group	(215) 566-3387	Oceana Naval Air Station, VA performance data enclosed in data package
Dr. Melinda Trizinsky Clean Sites Environmental Services	(703) 739-1217	Yuma Marine Corps Air Station, AZ performance data enclosed in data package
Debbie Yamamoto EPA Region 10	(206) 553-7216	Boomsnub/BOC Gases CERCLA site, WA (technology to be implemented in 1998)
Paul Marchessault EPA Region 1	(617) 573-5793	Otis National Guard Air Base CERCLA site, technology demonstrated at site and selected in ROD for implementation at one of the largest groundwater cleanup projects in the US

Reprint of paper from "In Situ Remediation of the Geoenvironment," Geotechnical Special
Publication No. 71, American Society of Civil Engineers, Reston, Va, 1997

In-Situ Groundwater Remediation Using In-Well Stripping: Modeling, Design and Performance Data

Tom McKeon¹, Gaynor Dawson², Stan Peterson³

ABSTRACT

In-well stripping is a patented design for in-situ remediation of VOCs in groundwater as an alternative to pump/treat systems. In the process of initial development and commercialization of the technology, a variety of modeling and design tools have been developed to assist in system design and evaluation. The existing performance data have been used to demonstrate the in-well stripping system effectiveness and validate the modeling and system design tools. This paper presents a summary of in-well stripping technology along with a general description of design tools and performance data.

INTRODUCTION

In-well stripping is a patented (U.S. Patent No. 5,425,598) design for in-situ remediation of VOCs in groundwater as an alternative to pump/treat systems. Modeling and design tools have been developed to assist in system design and evaluation. Performance data have been collected at a variety of sites which cover a range of hydrogeologic conditions. The existing performance data have been used to demonstrate the in-well stripping system effectiveness and validate the modeling and system design tools.

In-well stripping technology relies on over-pressurized air to circulate and clean water flowing through a well. A pressurized air delivery line is placed in the well to deliver a stream of air bubbles into the well. The rising column of bubbles acts as an air-lift pump pushing the combined stream of air/water up the casing while drawing contaminated water in through the extraction screen. As the air bubbles and water move up through the casing, volatile contaminants vaporize and transfer from the dissolved state to that of a free vapor in the air bubbles. A vacuum is applied at the well head to recovery the vapors at a point above the packer (i.e., a shale trap packer or other packer) and the contaminant vapors are drawn off for treatment. A typical layout of a stripping well is shown in Figure 1.

¹Senior Engineer, Project Performance Corp., 16935 SE 39th St, Bellevue WA 98008

²Vice President, Project Performance Corp, 64209 E Grover PR, West Richland WA 99353

³Senior Geochemist, Project Performance Corp, 70 Fairway Rd, Mesa WA 99343

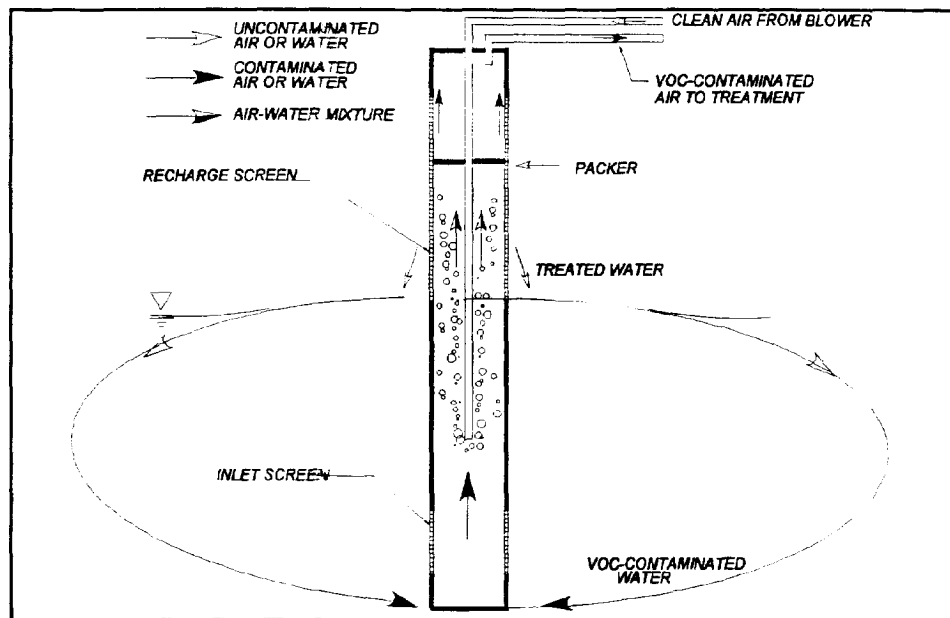


Figure 1 Example In-well Stripping Configuration

The casing is perforated above and below the packer with an upper screen (the recharge screen) to allow the groundwater to flow back into the aquifer. Modeling studies (Gvirtzman and Gorelick, 1992) have predicted and experimental studies (Stallard, et. al. 1996) have verified that the reinfiltrating water completes a toroidal circulation pattern within the aquifer. This permits a large portion of the water to be drawn back in and reprocessed. The water pumping rates are selected to allow for a sufficient number of cycles through the well to achieve the desired level of removal. The water discharging from the treatment well contains elevated levels of dissolved oxygen (typically at or near saturation) and the treatment process is expected to accelerate aerobic biodegradation of degradable hydrocarbons through the delivery of oxygen to the aquifer.

The modeling and design tools developed include analysis of hydrogeologic circulation patterns, mass transfer efficiency of the in-well stripping, and geochemical stability calculations.

GROUNDWATER MODELING

The groundwater modeling tools developed for system design are based on an analytical model of the three-dimensional flow patterns and capture/treatment zones of partially-penetrating wells. The starting point for the model development is a standard analytical solution for three-dimensional flow to a point source/sink (located at $x=y=z=0$) in an infinite porous media (e.g., Strack 1989):

$$\Phi = \frac{-Q}{4 \pi} \frac{1}{\sqrt{x^2 + y^2 + z^2}} + \text{Constant} \quad (\text{Eq. 1})$$

where

Φ = discharge potential (L^2/T)

Q = discharge rate for the point (L^3/T)

This analytical solution is converted to a solution that corresponds to withdrawal at a constant flow rate over a line segment with a constant unit withdrawal rate. The result is then integrated over a finite interval in the z -direction ($z = \pm C$) to yield an equation for an extraction well with a partially-penetrating screen in an infinite aquifer. The resulting discharge potential equation is then (de Marsily 1986):

$$\Phi = \frac{L}{4 \pi} \ln \frac{(z + c) + \sqrt{x^2 + y^2 + (z + c)^2}}{(z - c) + \sqrt{x^2 + y^2 + (z - c)^2}} \quad (\text{Eq. 2})$$

where L = withdrawal rate per unit length of line segment (L^2/T)

Superposition is used to create boundary conditions of an aquifer with upper and lower boundaries. Superposition is also used to include effects of a regional gradient. Once the appropriate mathematical function for the discharge potential of a partially-penetrating well is defined, the three-dimensional velocity field is derived by analytically differentiating the potential function with respect to the x , y , and z coordinates. This yields analytical expressions of the velocity vector (x , y , z components) as a function of the pumping rate, regional gradient, hydraulic conductivity, screened interval, and aquifer thickness (Philip and Walter 1992, Cho 1993, and McKeon and Wagner 1994).

The velocity field is then used to calculate particle pathlines by integration of particle trajectories through the velocity field. By starting particles along horizontal and vertical lines located up gradient from the extraction well, it is then possible to trace the three-dimensional shape of the capture zone to the extraction well. The effects of anisotropic hydraulic conductivity are incorporated by appropriate scaling of the coordinate system. The problem is first solved for an isotropic media then appropriately scaled to obtain the solution for the anisotropic media.

Dimensional analysis of the geometric and flow parameters that govern the characteristics of the system can be used to summarize the model simulation results (e.g., McKeon and Wagner 1994). Reducing the model simulation results to basic dimensionless parameters allows the design process to quickly examine a wide range of potential site conditions that may be encountered and develop appropriate system design parameters for specific site conditions. Dimensional analysis of the flow system around a recirculating well shows that the size of the treatment zone is related to the thickness of the plume, pumping rate, hydraulic gradient, hydraulic conductivity and

anisotropic ratio. In addition, the diameter of the treatment zone can be predicted as a scalar multiple of the plume thickness.

MASS TRANSFER DESIGN

The mass transfer can be characterized by a mass removal factor (MRF) which is defined as the concentration flowing into the treatment well divided by the concentration flowing out of the well. For example, if the initial concentration is 1 ppm and the outlet concentration is 0.2 ppm, then the MRF is $1/0.2 = 5$. The physical parameters that will affect the calculated mass removal factor are: air/water ratio, stripping column height, Henry's law constant, temperature, and bubble size.

When the stripping column is of sufficient height, equilibrium vapor phase and water phase concentrations are reached, the equilibrium is a linear function of the Henry's law constant and the air/water ratio. An equation that can be used to calculate the MRF is derived by Gvirtzman and Gorelick (1992) and Pankow et al. (1993):

$$MRF = [(H/RT \times AWR) + 1] \quad (Eq. 3)$$

where:

MRF =equilibrium mass reduction factor

H =Henry's law constant (atm-m³/mole)

R =gas constant (8.2×10^{-5} atm-m³/mole-K)

T =absolute temperature in degrees Kelvin (°K)

AWR =air/water ratio (volume ratio with the gas phase volume based on groundwater temperature and a pressure of about 1 psig)

The above equation gives the maximum possible mass reduction factor for a given chemical and air/water ratio. Additional mass transfer calculations are also useful to evaluate the kinetics of mass transfer within the air-lift bubble column. These calculations need to consider residence time in the well, compound volatility, bubble size, and equilibrium partitioning. The calculations are based on mass transfer rates from a water/bubble flow system where the gas and liquid streams are flowing together in the same direction (Zhou et al.1994 and Gvirtzman and Gorelick 1992). These calculations indicate that for most practical applications (bubble diameters in the range of 0.25 to 0.5 inches and contact lengths of 10 to 15 feet), the residence time within the well is sufficient to achieve 95 % or more of the equilibrium mass transfer value.

GEOCHEMICAL CONSIDERATIONS

Waters are often in equilibrium with calcium carbonate (also known as calcite or CaCO₃). Calcium carbonate can readily precipitate from solution if the pH of the water increases. The pH may rise and calcite precipitate as the system strips CO₂ from the groundwater concurrently with the VOCs. Injecting CO₂ into the air delivery lines will prevent this precipitation. The first step is to determine if calcite precipitation is likely to occur. A spreadsheet has been developed that computes calcite equilibrium and the quantity, if any, of CO₂ that should be injected to prevent calcite precipitation. Further, the spreadsheet provides a cost estimate for CO₂ usage and the expected pH

rise if no CO₂ is injected. Several of the equations and computations used in the spreadsheet are detailed below.

Even though groundwater is in equilibrium with calcite, calcite will not precipitate unless the pH rises upon stripping. The pH will rise if the subsurface partial pressure of CO₂ is higher than the partial pressure of CO₂ in the atmosphere. During stripping, the groundwater will equilibrate with atmospheric partial pressures of CO₂ (10^{-3.5}) and if subsurface partial pressures are higher, CO₂ will be stripped from the groundwater resulting in a pH rise. In the spreadsheet, the subsurface partial pressure of CO₂ is computed to determine if the potential for a pH rise with commensurate calcite precipitation is present.

The reaction involving CO₂ is given as follows:



where the log of the equilibrium constant (K) is 18.16. Rearranging this relation allows the determination of the reaction constant K as:

$$\text{PCO}_2 (\text{H}_2\text{O})/(\text{CO}_3^{2-}) (\text{H}^+)^2 = K \quad (\text{Eq. 5})$$

where () represents activities and PCO₂ is the partial pressure of CO₂ (g).

Given a measured pH and a carbonate activity computed from the spreadsheet, the spreadsheet calculates the subsurface partial pressure of CO₂ according to the previous relation. The spreadsheet then computes the anticipated pH rise when stripping by assuming equilibrium with an atmospheric partial pressure of 10^{-3.5} atmospheres. It may occur that the pH rises enough to cause precipitation in a solution that was initially undersaturated with calcite.

The solubility product (K_{sp}) for calcite varies with temperature and can be computed by the method of Plummer and Busenberg (1982):

$$\text{Log } K_{\text{sp}} = -171.9065 - 0.077993T_k + 2839.319/T_k + 71.595 \log T_k \quad (\text{Eq. 6})$$

where: $T_k = 273.15 + T^\circ\text{C}$

and T_k is the temperature in degrees Kelvin and $T^\circ\text{C}$ is degrees Centigrade. These corrections apply for temperatures between 0°C to 100°C.

The ionic strength of the solution is computed combining equations by Griffin and Jurinak, (1973) to arrive at:

$$I = \text{TDS}/50,394 \quad (\text{Eq. 7})$$

where: TDS = Total Dissolved Solids (mg/l)

I = ionic strength (moles/l)

The activity coefficient (f) is calculated by:

$$-\log f = AZ^2 \left[\left(I^{1/2} / (1 + I^{1/2}) \right) - 0.3I \right] \quad (\text{Eq. 8})$$

(where A is a constant and Z is equal to the valence of the ion) and is used with concentration data to compute the activities of the carbonate and calcium ions.

Next, an equation derived from the alkalinity and dissociation constants of carbonic acid is applied to compute the concentration (M) and then the activity of the carbonate ion.

$$\text{MCO}_3^{2-} \text{ (mmole/l)} = [\text{Alkalinity (mg/l CaCO}_3\text{)} / 50 \text{ mg/meq}] / [((\text{H}^+) / 10^{-10.3}) + 2] \quad (\text{Eq. 9})$$

To calculate the saturation index (S.I.) it is necessary to compute the activities of the calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions. An activity product (AP) is then computed by multiplying the activity of the calcium ion by the activity of the carbonate ion. A S.I. is calculated by taking the log of the activity product over the solubility product (SP) as shown below.

$$\text{Saturation index (S.I.)} = \log[(\text{AP})/(\text{SP})] \quad (\text{Eq. 10})$$

Knowing the S.I., it is possible to determine whether the groundwater is currently oversaturated, in equilibrium, or undersaturated with calcite, as indicated below. It is also possible to compute the CO_2 necessary to prevent calcite precipitation.

S.I. > 0 calcite is oversaturated and will precipitate from solution

S.I. = 0 calcite is in equilibrium and will precipitate if the pH rises

S.I. < 0 calcite is undersaturated and will not precipitate unless the pH rises sufficiently

The spreadsheet has been verified and validated by comparison with geochemical codes and laboratory data. Predictions are generally within + /- 1% of the values found in the laboratory and computed by the geochemical codes.

Recycling the air can reduce the costs associated with CO_2 additions. Recycling is accomplished by running the off gas through the vacuum blower and then through a granular activated carbon (GAC) unit. The effluent gas from the GAC unit then goes through the injection blower to be reinjected into the treatment well. Based on operating data from several projects, it is estimated that recycling reduces the CO_2 requirement to approximately 1 to 5 percent of the total computed CO_2 requirement for an open loop system.

PERFORMANCE DATA

Performance data are available from operating in-well stripping systems covering a range of site conditions. An example data set is presented for a single project (site

background, geologic and hydrogeologic conditions, and concentration reduction profiles). Additional performance data for other sites is also presented along with references for further information.

The case study presented is for a light industrial site in northern Idaho located in the city of Coeur d'Alene. Groundwater beneath the site is contaminated with TCE as a result of past waste disposal practices at several different industries in and around Coeur d'Alene. The layout of site monitoring wells includes one well at the outlet of the treatment well (screened over the water table), one well 19 feet away (screened from 5 to 15 feet below the water table) and another 89 feet away (screened from 10 to 20 feet below the water table). The depth to groundwater at the site is about 190 feet below ground surface.

The site geology consists predominantly of unconsolidated sand to a depth of greater than 405 ft. Few wells in the area have been drilled deep enough to reach bedrock. The sediments are nearly homogenous except they gradually grade from gravel at the top to medium and fine sand below the water table. A few thin discontinuous clay layers are also present below the water table. Based on the boring logs available, the aquifer extends to bedrock which is at greater than 405 feet below ground surface at the site. The productivity of this aquifer is high and the aquifer has been designated a Sole Source Aquifer by the EPA. In the Coeur d'Alene vicinity, the horizontal movement is estimated to be approximately 5 ft/day (Painter, 1996).

The primary VOC present in groundwater at the site is TCE. The maximum groundwater concentration of TCE identified at the site was 1510 $\mu\text{g/L}$ in a sample taken during drilling. A sample taken just before the system began operating (October 22 1996) had a concentration of 900 $\mu\text{g/L}$. An important consideration at this site is the equilibrium of calcite (CaCO_3) with respect to the groundwater. Groundwater at the site is computed to be in geochemical equilibrium with calcite and raising the pH can cause calcite scale formation.

The treatment well is constructed with 6-inch casing and screens similar to Figure 1 except that a 4-inch inner eductor pipe is added where the air-lift pumping and vapor stripping occur. The inlet screen is placed at a depth of 30 feet below the water table and the recharge screen is placed above the water table. The system operates at a water pumping rate of 35 gpm.

The monitoring data collected over the first five months of system operation are presented in Figure 2. The concentration reductions observed in nearby monitoring wells are quite dramatic. The closest monitoring well (MW-1, 19 feet away) has shown TCE concentrations reduced by 98 percent in the initial operating period. The most distant monitoring well (MW-3, 89 feet away), has shown concentration reductions of 96 percent in over 12 months and the downward trend in concentration appears to be continuing. Based on the observed concentrations reductions (96% reduction at about 89 feet away), the diameter of treatment zone is more than 6 times the distance from the inlet screen to water table.

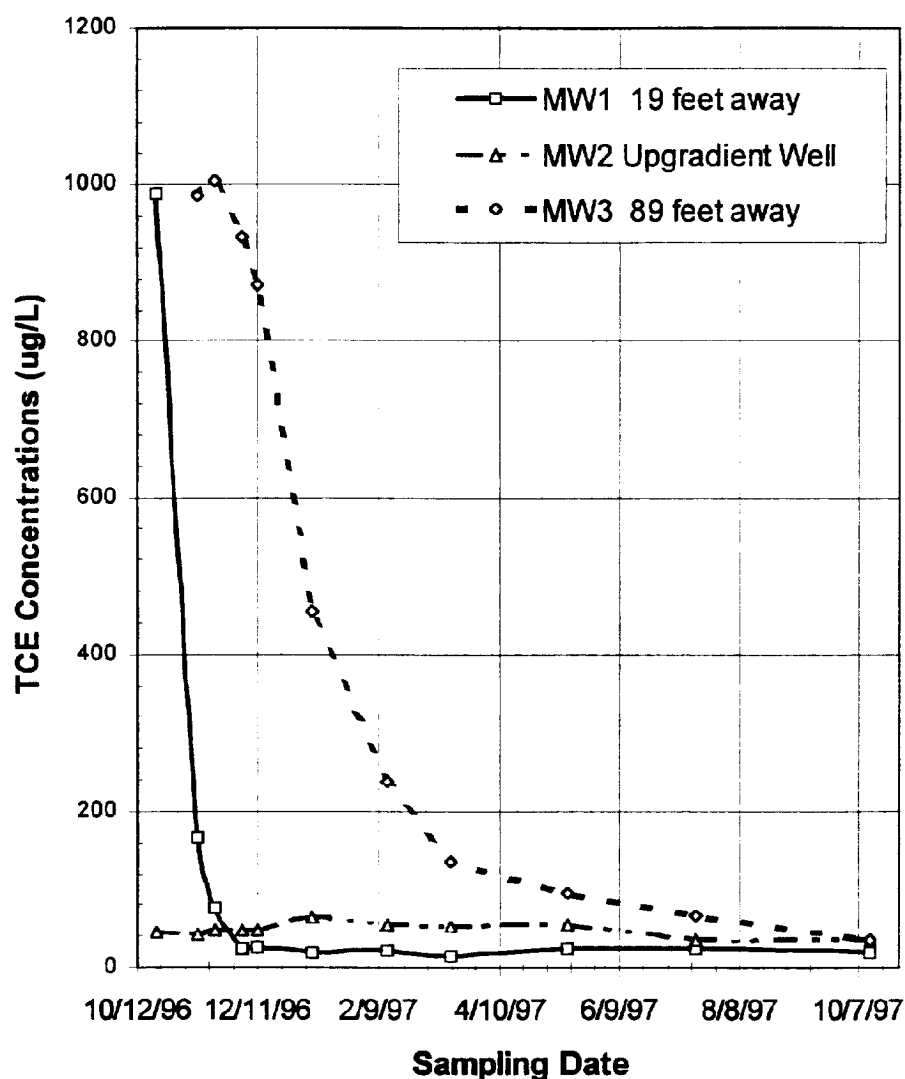


Figure 2 Observed TCE Concentration Reductions
In-well Stripping Installation in Coeur d'Alene, ID

Additional performance data are also available from other projects throughout the United States. For brevity, only summary data for other operating systems are presented (see Table 1). The concentration reduction profiles demonstrating system performance for three other sites are also presented from projects at Edwards Air Force Base (AFB), Fairchild AFB, and Oceana Naval Air Station (NAS) in Figures 3,

4 and 5, respectively. Several of these sites have included extensive monitoring networks with frequent sampling.

For the system at Edwards AFB the diameter of the treatment zone was measured (based on VOC concentration reductions of 80%) at greater than 100 feet, more than 4 times the aquifer thickness. The diameter of the treatment zone of the system at Oceana NAS was measured (based on VOC concentrations reductions of 90%) at greater than 80 feet which is approximately 6 times the aquifer thickness. The diameter of the treatment zone of the system at Fairchild AFB was measured (based on VOC concentrations reductions of 90%) at greater than 70 feet which is approximately 9 times the aquifer thickness. For other sites, the estimated treatment zone size has been measured based on increased dissolved oxygen levels as a tracer and at other sites the estimated treatment zone size is a modeling estimate because field monitoring data are not yet available during the early phase of system operation.

Table 1 Selected In-well Stripping Systems Installed - Summary of Design Information

Site Location/Setting	Geologic Conditions	Depth of Wells (feet)	Water Pumping Rate (gpm)	Hydraulic Conductivity (cm/sec)	Measured/Estimated Radius of Treatment Zone (feet)
CA, AFB Site	Fine sand/silty sand	50	5 to 8	2×10^{-3}	>50 *
France, Industrial Site	Medium/coarse sand	60	120	5×10^{-2}	115*
AZ, MCAS Site	Fine sand	92	20	1×10^{-3}	75*
VA, Navy Site	Fine sand & silt	20	5	1×10^{-3}	>40*
ID, Industrial Plant	Sand, silt/clay layers	220	35	5×10^{-3}	90*
WA, AFB Site	Medium sand	14	5	8×10^{-2}	35*
AZ, Landfill Site	Medium sand	230	150	2×10^{-2}	200**
MA, AFB Site	Medium /fine sand	260	200	5×10^{-2}	150*
WA, Landfill Site	Sand and gravel	90	250	4×10^{-1}	75**
CA, Industrial Site	Medium/coarse sand	90	90	2×10^{-2}	90*
WA, Industrial Site	Sand/silty sand	40	30	1×10^{-2}	80**

* measured radius of treatment zone: ** estimated radius pending collection of more data

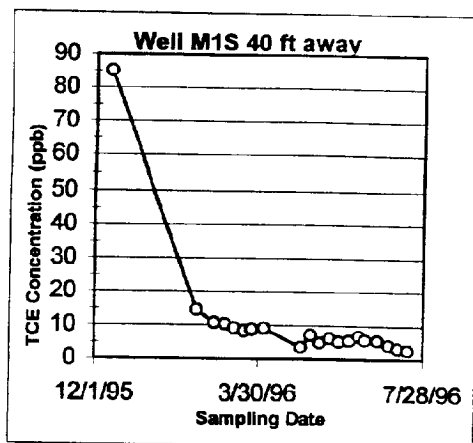


Figure 3a

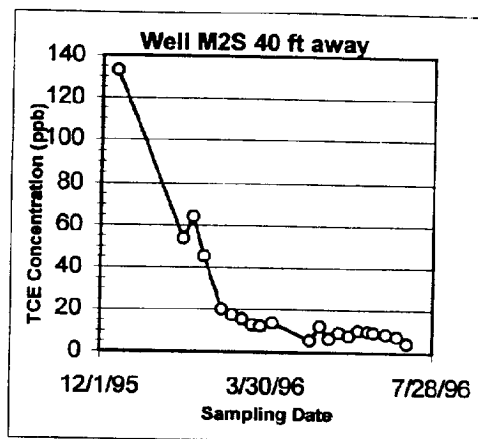


Figure 3b

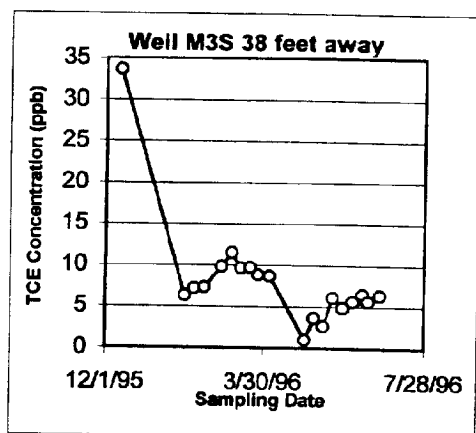


Figure 3c

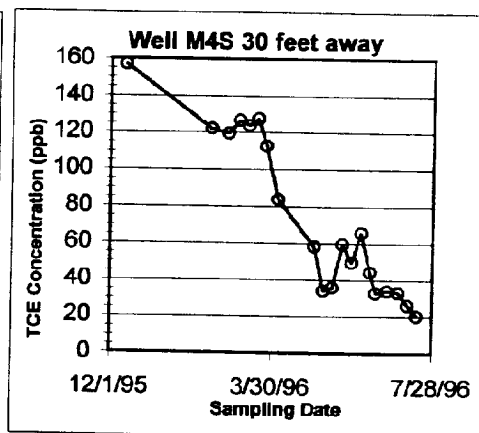


Figure 3d

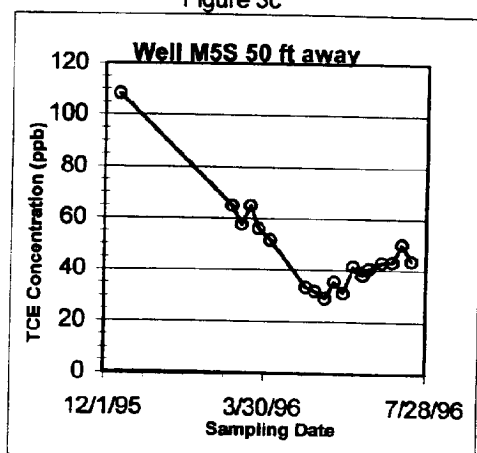


Figure 3e

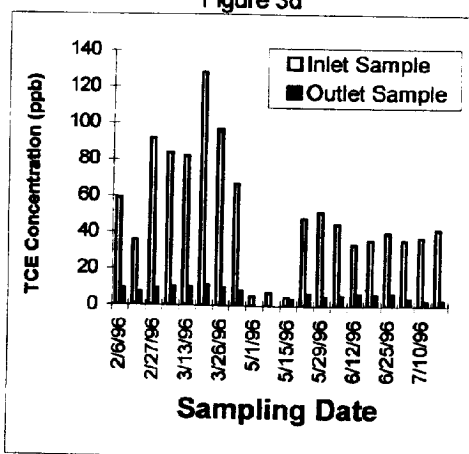


Figure 3f

Figure 3. Concentration Reduction Profiles, In-well Stripping System at Edwards AFB

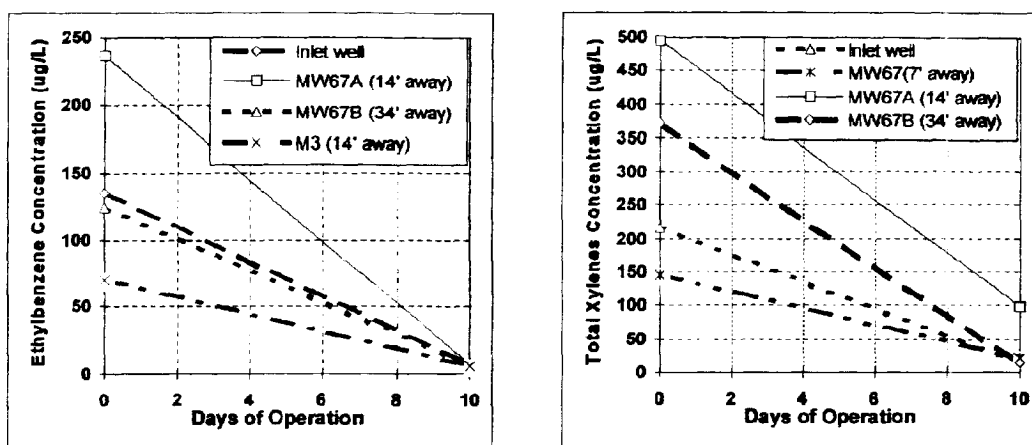


Figure 4. Concentration Reduction Profiles
In-well Stripping System at Fairchild AFB

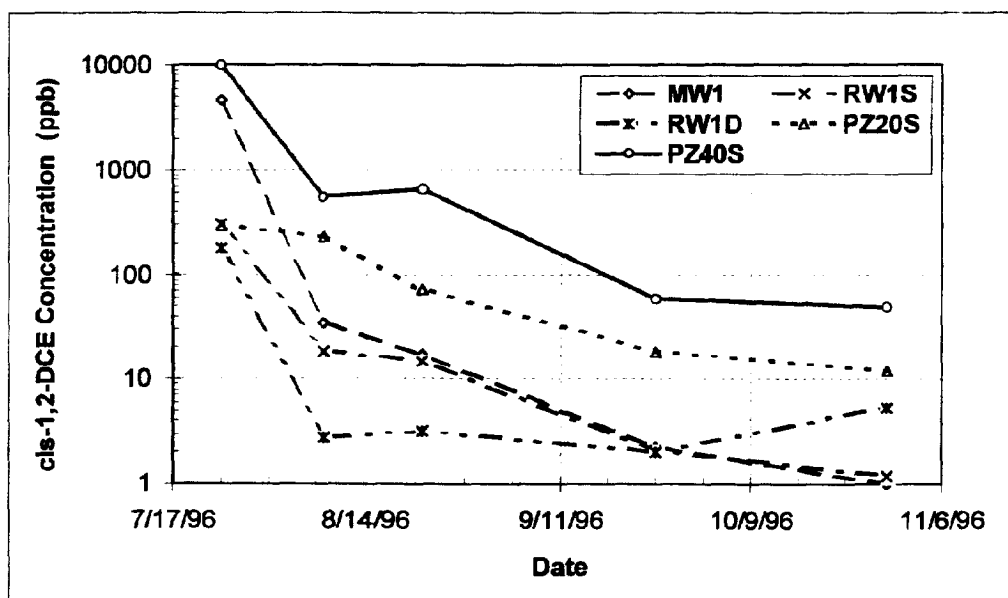


Figure 5. Concentration Reduction Profiles,
In-well Stripping System at Oceana NAS

Additional information on the in-well stripping systems at Edwards AFB, Fairchild AFB and Oceana NAS are presented in Battelle (1996), EG&G (1996), and CH2MHILL (1997). The existing performance data illustrate that in-well stripping systems can be effective under a range of hydrogeologic conditions. Some of the key performance characteristics presented in the data include the following:

- the system can achieve cleanup goals in the low ppb range
- the system generates a circulation pattern that covers a wide area (radii of treatment zones have been measured in excess of 100 feet)
- the system operation is very robust and can be applied to a wide range of hydrogeologic conditions
- performance data generally indicate dramatic concentration reductions (90 percent and more) within the first several months of operation

COMPARISON OF DESIGN PARAMETERS AND PERFORMANCE DATA

The most important system design parameters with respect to efficient operation of in-well stripping are related to

- the circulation patterns established in the aquifer
- the stripping efficiency within the stripping well and
- the evaluation/control of potential calcite precipitation.

The design process needs to use estimates of key hydrogeologic conditions which affect the size of the circulation pattern. The estimated hydrogeologic parameters always contain uncertainty due to heterogeneity and potential errors/biases in measured parameters. The system design tools typically predict that the diameter of the circulation zone will be in the range of 4 to 8 times the distance from the inlet screen to the water table (depending on the anisotropy of the aquifer, the pumping rate, and the conductivity). The existing performance data indicate circulation zones sizes within this range. In general, the predicted and measured performance are comparable within the uncertainty associated with the hydrogeologic parameters used for site characterization.

The stripping efficiency within a stripping well has been measured at a number of sites using concentration data from the inlet and recharge zones of the well. These data have demonstrated concentration reductions in the range of 85 to 95 percent in a single pass through the treatment well. The performance depends on the volatility of the compound and the operating air-to-water ratio. For example, the system at Edwards AFB included weekly sampling for approximately 5 months and the average single pass (inlet of the well to recharge zone) concentration reduction throughout that period was 90 percent (see Figure 3f). The available sampling data indicate that the mass transfer design tools are sufficiently accurate for design purposes. This should be expected given the state of knowledge regarding mass transfer, empirical data available (i.e., mass transfer coefficients) and the ability to measure key parameters affecting the stripping efficiency.

The geochemical equilibrium calculations related to calcite solubility and the potential for precipitation have been used for a variety of site groundwaters. Water samples have been sparged and the measured increase in pH is accurately predicted with the design tools. Prior to system startup at Edwards AFB, a white scale formed on pipes and equipment placed below the water table indicating the potential for calcite precipitation. In addition, air stripping towers operating in the general area indicate frequent scale buildup. Regarding control of calcite precipitation through CO₂ addition, operating data from systems in California, Idaho, Arizona and Washington all indicate continuous operation with no indication of plugging or fouling of the well due to calcite precipitation.

The comparison of design versus performance data for a range of sites has demonstrated the validity of the system design tools. In general, the design tools provide a reasonable prediction of the system performance characteristics within the range of uncertainty associated with site characterization parameters.

ADDITIONAL ADAPTATIONS OF IN-WELL STRIPPING TECHNOLOGY

Several additional adaptations of the technology system have been developed to address other groundwater contamination problems beyond typical dissolved VOC plumes. These extensions of the treatment system allow in-situ treatment to be applied to a wider variety of groundwater contamination problems. The system adaptations include:

- a coupled in-well stripping/cometabolism project to demonstrate enhanced cometabolism of chlorinated compounds through addition of suitable substrates and nutrients
- a coupled in-well stripping/advanced oxidation project for in-situ treatment of selected organic compounds which are not strippable due to lower volatility
- an in-well stripping system coupled with suitable reactive media in an infiltration gallery for in-situ fixation of many common inorganic contaminants
- an in-well stripping system coupled with bioslurping to address sites with floating free product along with the dissolved plume

An in-well stripping system can also be easily implemented in a phased approach where wells are installed as a plume extent is identified. Operating the treatment wells during the remedial investigation has the obvious benefit of starting remedial actions early to remove VOC mass and help limit further plume migration. An in-well stripping system uses modular in-situ treatment and can be designed without extensive piping networks. These characteristics allow the system to be designed and installed using an Observational Method approach to site remediation that can be initiated before "complete" site characterization is done. Since some geologic and hydrogeologic systems can be very complex, it is impossible to completely characterize a site and an observational approach may often be the most cost-effective design/construction process.

SUMMARY

In-well stripping is a patented design for in-situ remediation of VOCs in groundwater using air-lift pumping and in-well stripping. A variety of modeling and design tools have been developed to assist in system design and evaluation. The existing performance data have been used to demonstrate in-well stripping effectiveness and validate the modeling and system design tools. Some of the key performance characteristics presented in the data include the following:

- the system can achieve cleanup goals in the low ppb range
- the system generates a circulation pattern that covers a wide area (radii of treatment zones have been measured in excess of 100 feet)
- the system operation is very robust and can be applied to a wide range of hydrogeologic conditions
- performance data generally indicate rapid concentration reductions (90 percent and more) within the first several months of operation

REFERENCES

- Battelle, 1996. Performance Assessment of the In-Well Vapor-Stripping System. Prepared by Pacific Northwest National Laboratory, prepared for U.S Department of Energy.
- CH2MHILL, 1997. Final Report on the Pilot Test of In-situ Aeration Technology at RCRA SWMU 24, Oceana Naval Air Station. Prepared for Department of the Navy, Atlantic Division, Naval Facilities Engineering Command.
- Cho J.S., 1993. A three-dimensional air flow model for soil venting: Superposition of analytical functions, *Jou. of Hazardous Materials*, 35, pp. 31-51.
- de Marsily, G., 1986. *Quantitative Hydrogeology*. Academic Press, New York, 440 pp.
- EG&G, 1996. In-well Stripping Demonstration at Fairchild Air Force Base: Project Summary Report. Prepared for Civil Engineering Squadron Environmental Flight, Fairchild Air Force Base.
- Griffin, R.A. and J.J. Jurniak, 1973. Estimation of activity coefficients from electrical conductivity of natural aquatic systems and soil extracts. *Soil Science*, 116, pp. 26-30
- Gvirtzman, H. and S. Gorelick, 1992. The concept of in-situ vapor stripping for removing VOCs from groundwater. *Transport in Porous Media*, 8, 71-92.
- McKeon, T.J. and C. Wagoner, 1994. Analytical evaluation of 3-D capture zones for partially-penetrating wells, *International Conference on Analytical Element Modeling of Groundwater Flow*, Indianapolis, Indiana, pp 71-77.

Painter, B., 1996. Idaho Division of Environmental Quality hydrogeologist- Personal conversation between Jim De Smet of Quantum Environmental Engineering and Brian Painter.

Pankow J., R. Johnson, and J. Cherry, 1993. Air sparging in gate wells in cutoff walls and trenches for control of plumes of volatile organic compounds (VOCs), *Ground Water*, 31(4), pp 654-663.

Philip, R.D. and G.R. Walter, 1992. Prediction of flow and hydraulic head fields for vertical circulation wells, *Ground Water*, 30(5), pp 765-773.

Plummer, L. N., and E. Busenberg, 1982. The solubilities of calcite, aragonite and vaterite in CO₂-H₂O solutions between 0 and 90°C, and an evaluation of the aqueous model for the system CaCO₃-CO₂-H₂O. *Geochemica et Cosmochimica Acta*, Vol. 46: pp. 1011-1040.

Stallard, W., K. Wu, N. Shi and M. Corapciogla, 1996. Two-dimensional hydraulics of recirculating ground-water remediation wells in unconfined aquifers, *Jou. of Environmental Engineering ASCE*, 122(8), 692-699.

Strack, O.D.L., 1989. *Groundwater Mechanics*. Prentice Hall, New Jersey, 732 pp.

Zhou, H., D.W. Smith, and S.J. Stanley, 1994. Modeling of dissolved ozone concentration profiles in bubble columns. *Jou. of Environmental Engineering ASCE*, 120(4), 821-840.

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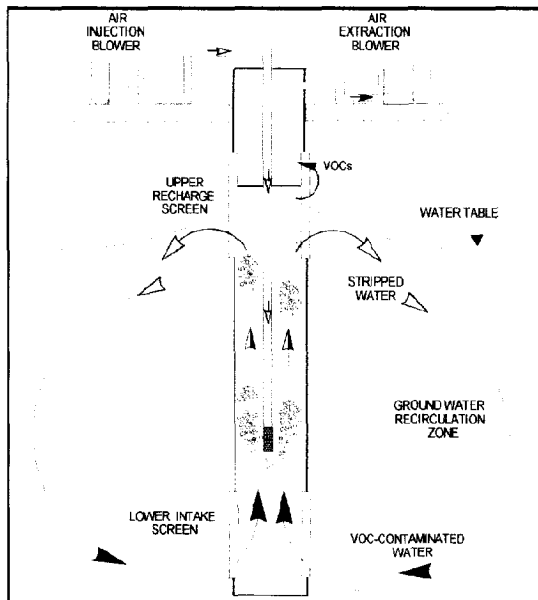
Project
Performance



IN-WELL VAPOR STRIPPING WITH PRESSURIZED RECIRCULATING WELL SYSTEMS

The concept of recirculating wells with in-well vapor stripping was developed and tested in the late 1980s as an alternative to pump and treat remedies for volatile organic compound (VOC) contamination in groundwater. In-well vapor stripping simplifies the treatment process by eliminating separate above-ground aqueous phase treatment.

Project Performance Corporation (PPC) staff have been involved in the design, installation, and startup of in-well stripping systems for the past four years. Under a license agreement for the patented Density Driven Convection (DDC) in-well stripping technology, PPC staff can design, install, and operate advanced systems to meet your remediation needs.



Patented In-Well Stripping System

ADVANTAGES OF RECIRCULATING WELL DESIGNS OVER PUMP AND TREAT SYSTEMS

- ✓ Requires Lower Capital and O&M Costs
- ✓ Reduces Operating Costs, Only Vapors are Pumped to Surface, Not Water
- ✓ Eliminates Need for NPDES Permits, Discharge Fees and Associated Sampling/Reporting Requirements
- ✓ Enhances Removal of Chlorinated Solvents Through Vertical Gradients and Aggressive Flushing of the Soil
- ✓ Enhances Bioremediation of Hydrocarbons Through Aeration of Treated Water
- ✓ Options Available for Recovery of Separate Phase LNAPLs and DNAPLs

In the DDC system, air is injected via an air line into the well casing. The air reduces the density of the water column within the well bore creating an upward vertical gradient within the wellbore that draws water in through the lower screen and pushes aerated groundwater out through the upper screen. This process creates a groundwater circulation cell within the aquifer surrounding the DDC well.

Over 50 full-scale systems have been installed to date. Cleanup time frame depends on the site geology. Several projects have completed site remediation in approximately 1 year, other sites in silt and clay formations have achieved cleanup goals in approximately 2 years.

Additional information on in-well vapor stripping systems is available by contacting PPC at the offices listed below.

Project Performance Corporation

64209 E Grover PR NE, West Richland, WA, 99353; Phone (509) 967-2347; Fax (509) 967-5709
16935 SE 39th St., Bellevue, WA, 98008; Phone (425) 643-4634; Fax (425) 649-0643

Staff at Project Performance Corporation (PPC) have been involved with the design, installation, and operation of pressurized recirculating wells from the start of development and commercialization efforts in the US. PPC staff have direct design, installation, and operational experience at numerous sites, some of which are summarized below.

Site Location/ Setting	Geologic Conditions	Depth of Wells (feet)	Depth to Water (feet)	VOC Concentrations (ppb)	Pumping Rate (gpm)	Gradient (ft/ft)	Hydraulic Conductivity (cm/sec)	Measured/ Estimated Radius of Treatment Zone (feet)
California, USAF Site (ref. 14)	Fine sand/ silty sand	50	27	100 to 300 TCE	5 to 8	0.005	2×10^{-3}	>50
France, Industrial Plant (ref. 9)	Medium/ coarse sand	60	8	5,000 to 10,000 PCE	120	0.007	5×10^{-2}	115
Arizona, USMC Site (ref. 19)	Fine sand	92	60	10 to 20 TCE	20	0.003	$\sim 1 \times 10^{-3}$	75
Virginia, Navy Site (ref. 16)	Fine sand/sandy silt & silt	20	3 to 5	10,000 DCE	5	0.002	$\sim 1 \times 10^{-3}$	> 40
Idaho, Industrial Plant (ref. 20)	Sand with silt/clay layers	220	190	900 TCE	35	0.006	$\sim 5 \times 10^{-3}$	90
Washington, USAF Site (ref. 15)	Medium sand with silt	14	8	10,000 TPHg	5	0.003	8×10^{-2}	35
Arizona, Landfill Site	Medium sand	230	130	100 TCE, 500 PCE	150	0.004	2×10^{-2}	200
Massachusetts, USAF Site (ref. 17)	Medium / fine sand	260	40	1,000 TCE	200	0.002	5×10^{-2}	150
Indiana, Industrial Plant	Medium/ fine sand	92	60	100 TCE	30	0.003	3×10^{-2}	75
Washington, Landfill Site	Sand and gravel	90	45	100 TCE	250	0.004	4×10^{-1}	75
California, Industrial Site	Medium/ coarse sand	90	60	20,000 total VOCs	90	0.005	2×10^{-2}	90
Wisconsin, Gas Station	Fine sand/ sandy silt	38	10	1,000 total BTEX	8	0.002	$\sim 5 \times 10^{-4}$	75
California, Navy Site	Sand to silty sand	80	10	500,000 total VOCs	70	0.0008	4×10^{-3}	170

Data illustrating the performance of pressurized recirculating well systems are presented in the attached case histories. For additional information contact PPC.

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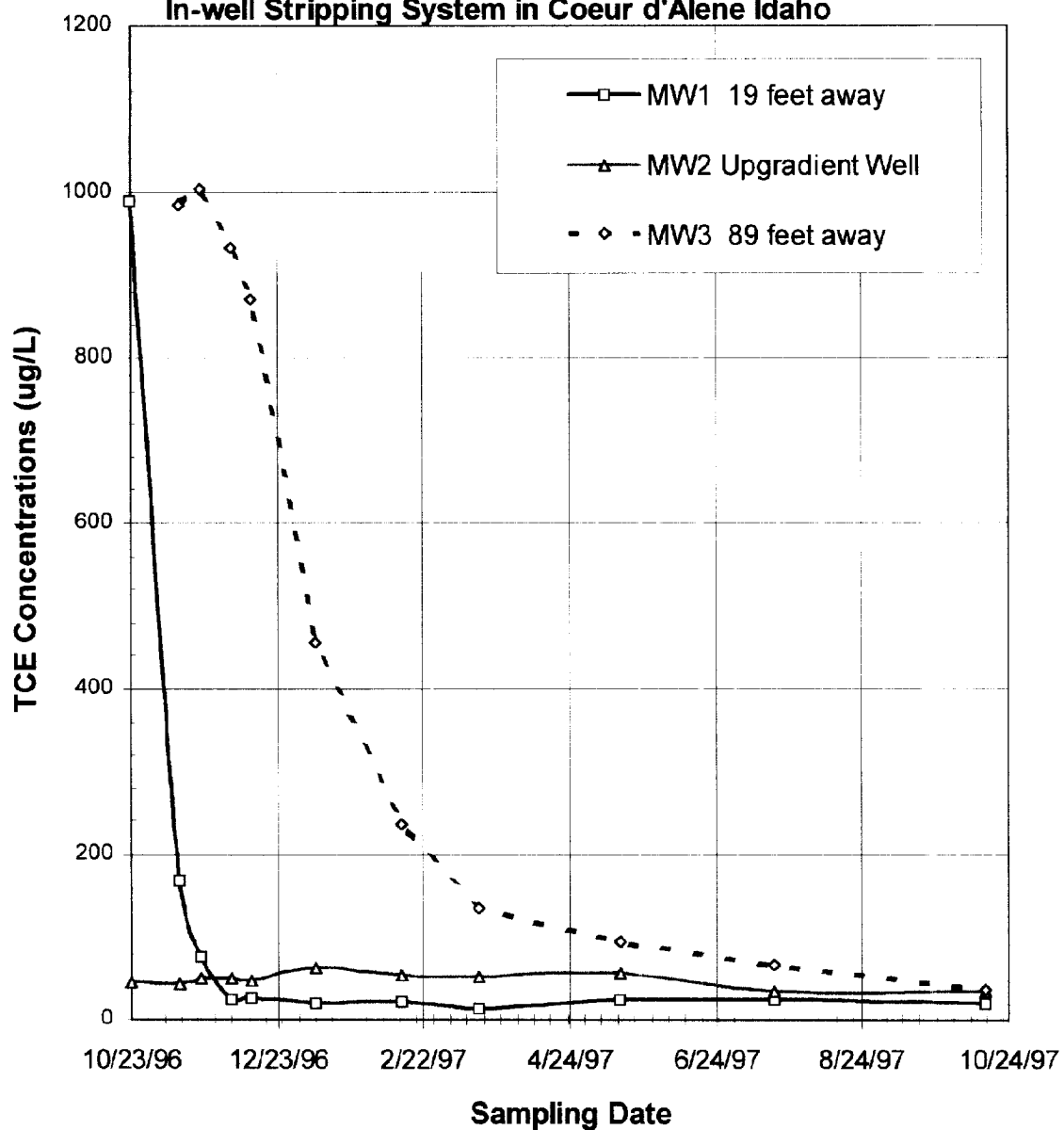
References

1. Environmental Protection Agency. 1995. "Unterdruck-Verdampfer-Brunnen Technology (UVB) Vacuum Vaporizing Well", *Site Technology Capsule*, EPA/5401r-95 1500A, Office of Research and Development.
2. Anon. 1995. "Profiles: Technologies at Work", *Environtech*, January, pp 5-6.
3. Bausmith, D.S. and D.J. Campbell. 1995. "Guidance For The Evaluation Of In-Situ Air Stripping Systems", U.S. Environmental Protection Agency.
4. Dawson, G.W. 1994. "In Well Treatment For Remediation of VOCs in Ground Water", *Defense Waste Cleanup Conference*, Washington D.C., October 4.
5. Gvirtzman, H. And O. Goren. 1995. "Feasibility Study of In-Well Vapor Stripping Using Airlift Pumping", *GWMMR*. Ground Water Publishing Co., Fall. Pp 155-161
6. Dagdigan, J.V. and N.A. Ihlenfeld. 1995. "Conquering the Cleanup Crisis", *The Military Engineer*.
7. Dawson, G.W. 1996. "Innovative Approaches to Remediation for VOCs Sites Using Recirculating Wells", *Sixth West Coast Conference On Contaminated Soils and Ground Water*. Newport Beach, CA. March 11-14.
8. Dawson, G.W., T.J. McKeon and T.S. Hawk. 1995. "In-Well Treatment For Remediation of VOCs in Ground Water", *I&EC Special Symposium*, American Chemical Society, Atlanta, GA. September 17-20.
9. Marceau, G and E. Gay. 1996. "Innovative Ground Water Treatment System" *NATO/CCMS 1996 Pilot Study*. February 12.
10. Schrauf, T.W., P.J. Sheehan and L.H. Pennington. 1994. "Alternative Method of Groundwater Sparging For Petroleum Hydrocarbon Remediation", *Remediation* Winter 1993/94.
11. Kim, I. and G. Ondrey. 1996. "Beyond Pump and Treat", *Chemical Engineering*. March, pp 30-36.
12. Cichon, E., P. Mantovani, and T. McKeon. 1996. "Rising Bubbles Lower Costs", *Soil and Groundwater Cleanup*. November, pp 40-43.
13. Dawson, G., and T. McKeon. 1996. "Accelerated Hydrocarbon Removal With the NoVOCs Process", *Proceedings of the 12th Annual Environmental Management and Technology Conference West*, Long Beach, CA, November 5-7.
14. Pacific Northwest National Laboratory. 1996. Performance Assessment of the In-Well Vapor-Stripping System, Pacific Northwest National Laboratory, Richland, WA.
15. Fairchild Air Force Base. 1996. In-well Stripping Demonstration at the Fairchild AFB: Project Summary Report, Fairchild Air Force Base, Spokane, WA.
16. CH2M HILL. 1997. Final Report on the Pilot Test of in-situ Aeration Technology at RCRA SWMU 24, Oceana Naval Air Station, Virginia Beach, VA, CH2M HILL, Reston, VA.
17. Jacobs Engineering Group. 1997. Draft Recirculating Well Pilot Tests for CS-10, System Evaluation, Jacobs Engineering Group, Otis ANGB, MA.
18. White, R. M. and R. A. Hiergesell. Airlift Recirculation Well Test Results – Southern Sector (U), Westinghouse Savannah River Company, Aiken, SC.
19. OHM. 1997. "Bimonthly Test Results, In-well Stripping System Pilot Study, MCAS, Yuma, SWDIV Contract No. N68711-93-D-1459, DO 79, OHM Corporation, Yuma, AZ.
20. McKeon, T, G. Dawson and S. Peterson. 1997. "In-Situ Groundwater Remediation Using In-Well Stripping: Modeling, Design and Performance Data", *In-situ Remediation of the Geoenvironment*, ASCE Geotechnical Special Publication No. 71, ASCE, Reston, VA

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Concentration Reduction Profile In-well Stripping System in Coeur d'Alene Idaho



IN-WELL STRIPPING AT NATIONAL GUARD BASE, MASSACHUSETTS

Stratified Plume Case Study

Setting

Former Otis Air Force Base
Large, deep, stratified plumes contaminated with TCE, PCE, and DCE
Sole source aquifer, highly productive
2-well system designed to demonstrate recirculating wells in this setting

Hydrogeology

Outwash deposits - primarily sand and fine gravels
Plume thickness - 120 feet (110 feet bgs - 230 feet bgs)
Aquifer thickness - 215 feet (15 feet bgs - 230 feet bgs)
Vadose zone thickness - 15 feet
Hydraulic conductivity - 160 feet/day
Horizontal gradient - 0.002

Contamination

TCE concentrations up to 2,700 ppb, average TCE of 1,234 ppb
PCE up to 84 ppb
DCE up to 130 ppb
System is installed in central area of a large plume

Initial Results

Monitoring wells established at seven depth intervals, from above the plume to the bottom of the aquifer.

Monitoring of inlet and outlet concentrations from the recirculating wells indicates a single pass stripping efficiency of between 88% and 94% TCE removal.

The large monitoring network of 18 wells shows an overall average reduction of 77% in TCE concentrations less than 3 months after startup. Sixteen of the wells show an average reduction of 90%. The other two wells show increases as the plume migrates toward the recirculating well extraction interval. Peak reductions of 98% are seen in some wells.

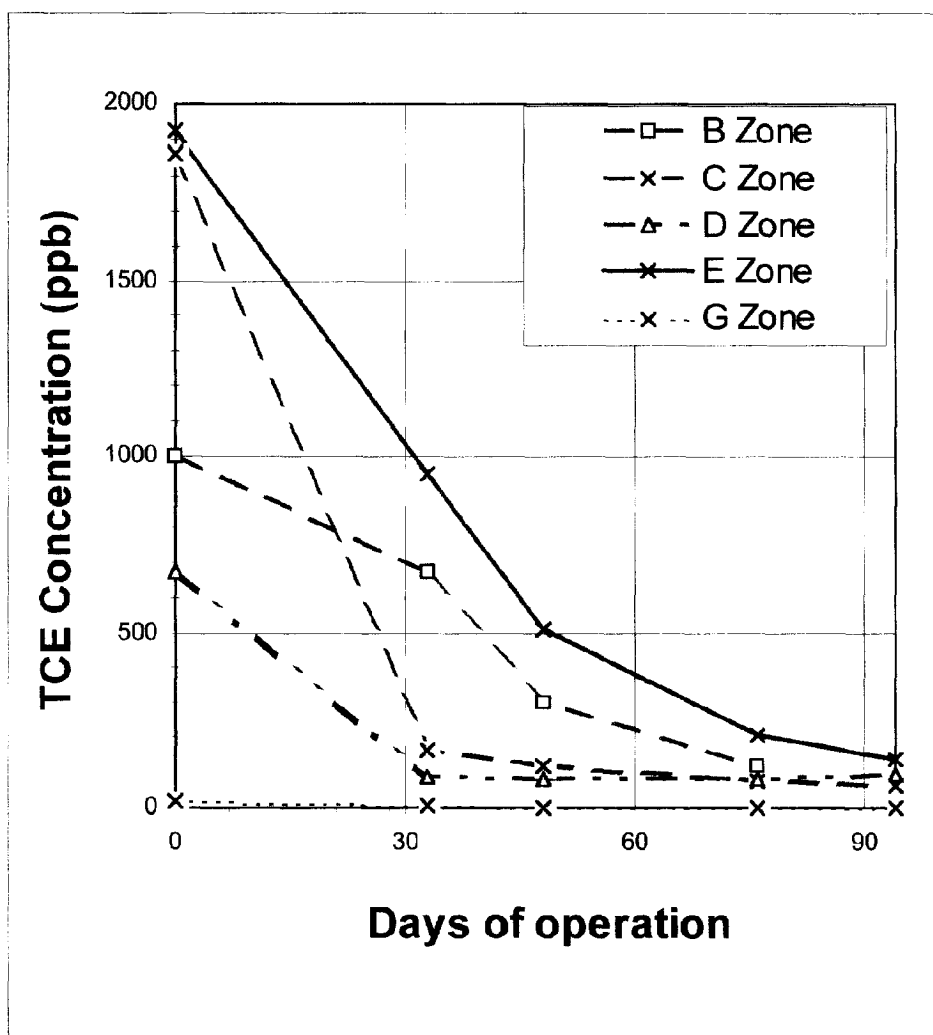
The top interval (A) has remained at non-detect, indicating that recirculation does not move contamination into uncontaminated upper zone.

Contamination in the bottom interval (G), below the level of the recirculating well inlet screens, is also decreasing, demonstrating that the circulation pattern extends below the wells.

Operation Details

- Two 30-hp regenerative blowers
- Pumping rate: 150 gpm in each well
- Air injection rate: 450 cfm in each well
- Air is treated and reinjected in a closed-loop; no air emission, no air discharge permits required

Concentration Reduction Profiles, National Guard Base, MA



IN-WELL STRIPPING MARINE CORPS AIR STATION (MCAS), ARIZONA

Plume Containment Case Study

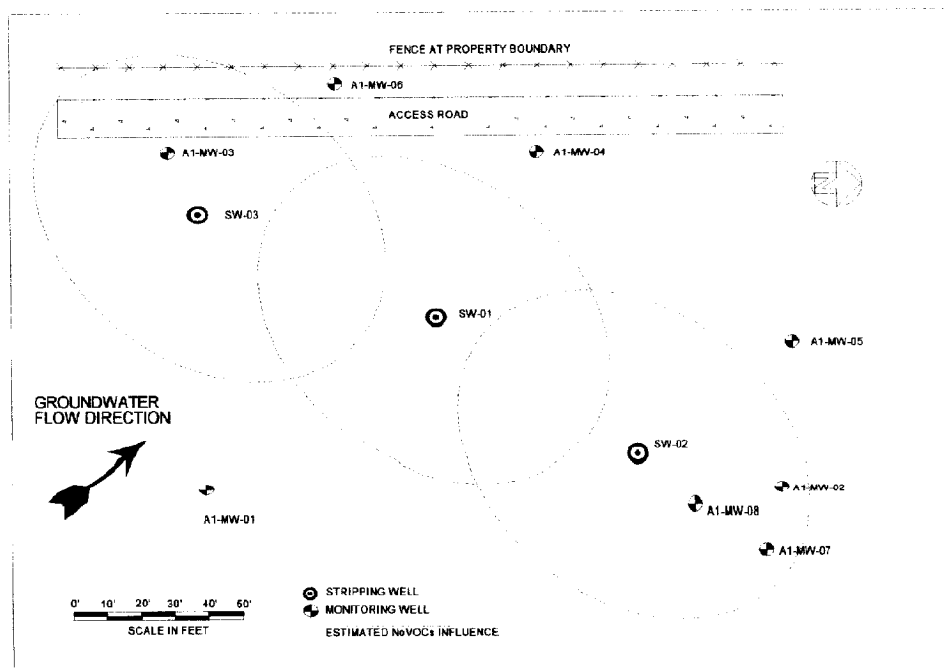
Setting Large plume contaminated with chlorinated solvents that has reached the site boundary
3-well system designed as a boundary containment system to prevent further downgradient plume migration

Hydrogeology Well-sorted fine sands with silt and clay lenses
Plume thickness >30 feet
Vadose zone thickness - 60 feet
Hydraulic conductivity - 3.9×10^{-2} cm/sec
Horizontal gradient - 0.0003 feet per foot

Contamination Plume source area contains up to 450 ppb TCE, 16 ppb PCE, and 170 ppb DCE
Downgradient edge contains approximately 15 ppb TCE, < 1 ppb PCE, and 20 ppb DCE

Inorganic Chemistry Alkalinity, pH, and calcium concentrations indicate groundwater is in equilibrium with calcite (potential for calcite precipitation exists)
Adding carbon dioxide into a closed-loop system has effectively prevented calcite precipitation/fouling

Well Location Map of Area 1 Site at MCAS



Initial Results Concentrations in two of the three wells have decreased from approximately 20 ppb 1,1,-DCE, and 15 ppb TCE to less than 1 ppb 1,1,-DCE and less than 1 ppb TCE.

VOCs decreased in monitoring well screened 20 feet below third well, indicating removal from depths below the bottom of the screen.

Measured stripping efficiencies > 95% on a single pass - system designed for multiple passes.

Water level data show groundwater containment curtain established to intercept plume.

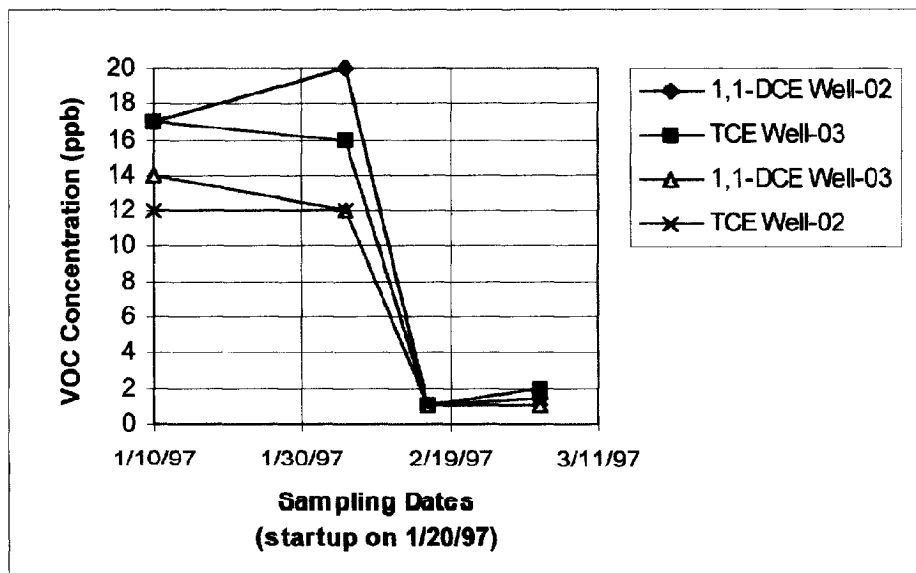
Mass balance: declining groundwater concentrations and measured VOCs in the air stream coincide, confirming treatment through removal.

Treated approximately 3,800,000 gallons of water to below MCLs.

Operation Details

- ▶ 10-hp positive displacement blower
- ▶ Pumping rates of approximately 20 gpm for each well
- ▶ Expected treatment radius > 50 feet/well

Concentrations at the Inlet Screens of the Recirculating Wells at MCAS, Arizona



IN-WELL STRIPPING AT CERCLA LANDFILL, PASCO, WASHINGTON

Plume Containment Case Study

Setting Chlorinated solvent plume is migrating from the landfill toward the town of Pasco, Washington, located 1.5 miles southwest of the landfill. A 2-well system was installed for boundary containment to prevent further down gradient plume migration

Hydrogeology Aquifer composed of gravelly sands with some silt
Plume thickness is approximately 45 feet
Vadose zone thickness - 60 feet
Hydraulic conductivity - 4.3×10^{-2} cm/sec
Horizontal gradient - 0.004 feet per foot

Contamination Treatment zone wells contained concentrations of 140 ppb TCE, 23 ppb PCE, 816 ppb 1,1,1-TCA, 1600 ppb cis-1,2-DCE, and 72 ppb cis-1,1-DCE.

Inorganic Chemistry Alkalinity, pH, and calcium concentrations indicate groundwater is in equilibrium with calcite (potential for calcite precipitation exists). Adding carbon dioxide into a closed-loop system has effectively prevented calcite precipitation/fouling.

Initial Results Significant concentration reductions were observed in treatment zone and down gradient wells. The effectiveness of the treatment system is readily apparent from a comparison of contaminant concentrations before startup, during a shutdown period for system upgrades, and after restarting following completion of upgrades.

Between March and December, 1997, concentration reductions observed in the wells with some of the highest initial concentrations were: TCE fell from 140 ppb to 4.7 ppb, PCE declined from 23 ppb to 0.5 ppb, 1,1,1 TCA decreased from 816 ppb to 170 ppb, cis-1,2-DCE plunged from 1,600 ppb to 9.3 ppb, and 1,1-DCE fell from 72 to 4.5 ppb. Down gradient concentrations of all contaminants analyzed fell to below regulatory limits. Figures 1 and 2 indicate the decreases in concentration over time for two of the contaminants in the treatment zone. Percentage decreases for contaminants are presented below.

- 97% reduction in TCE
- 98% reduction in PCE
- 79% reduction in 1,1,1 TCA
- 99% reduction in 1,2-DCE
- 94% reduction in 1,1-DCE

Operation Details

- ▶ 2 30-HP regenerative blowers
- ▶ Pumping rates of approximately 60-70 gpm for each well
- ▶ Treatment radius > 90 feet/well; greater than two times the plume thickness
- ▶ Closed-loop treatment system (no air emissions)

Figure 1
1,1,1-TCA in Treatment Zone Wells

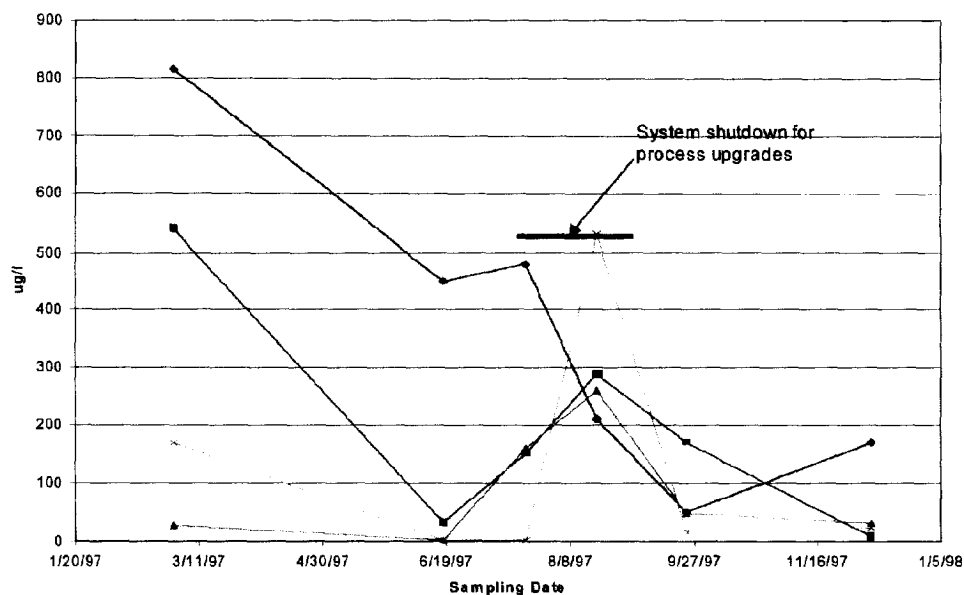
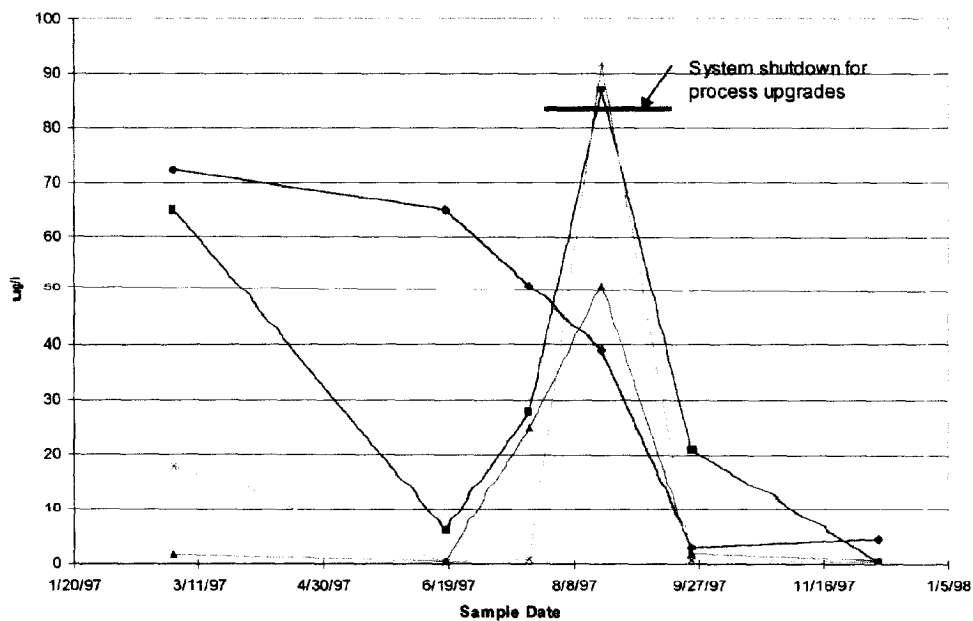


Figure 2
1,1-DCE in Treatment Zone Wells

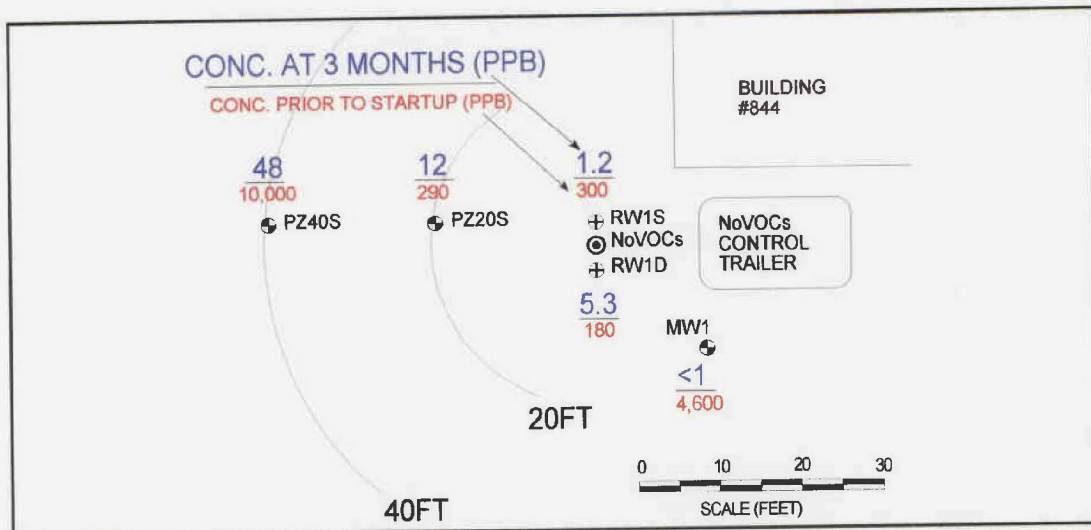


IN-WELL STRIPPING SYSTEM, NAVAL AIR STATION (NAS), VIRGINIA

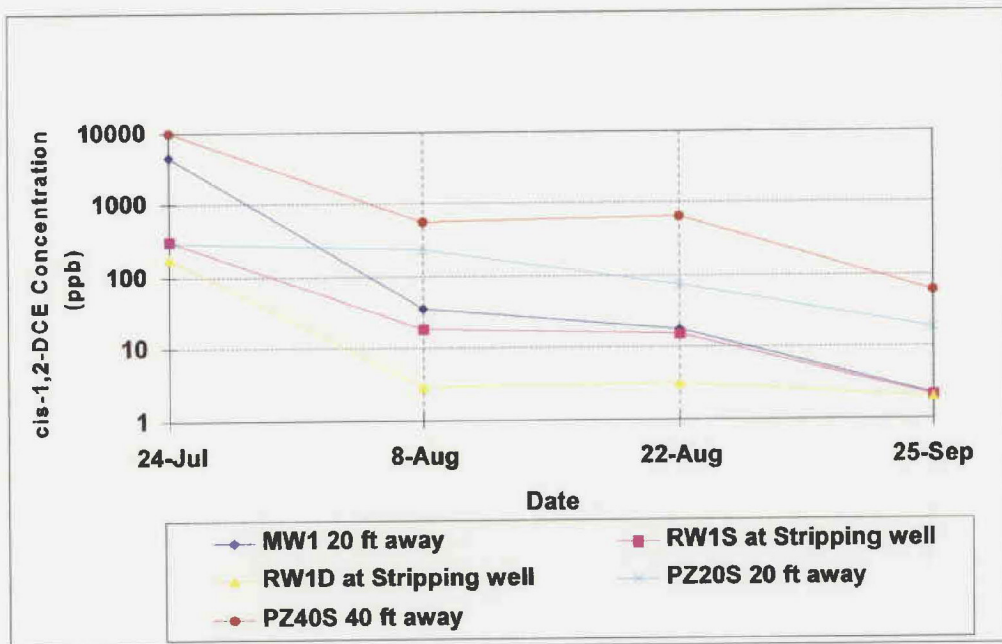
DCE Case Study

Setting	Naval Air Station, Virginia, single well pilot installation
Hydrogeology	Fine sand with silt, hydraulic conductivity $\sim 1 \times 10^{-3}$ cm/sec Saturated thickness - 15 feet Hydraulic gradient - 0.007 ft/ft Vadose zone thickness - 3 to 5 ft.
Contamination	cis-1,2-DCE - peak concentrations as high as 10,000 ppb Lower levels of BTEX and TPH present Primary objective of hot-spot mass removal
Inorganic Chemistry	Dissolved iron - 80 ppm
Results	Pumping rate - 5 gpm Period of operation - 3 month pilot operation Radius of influence greater than 40 feet, about 3 times plume thickness BTEX reduced to levels below or near detection limits Maximum 1,2-DCE concentration reduction - 99+ % Most wells within treatment zone have reached 1,2-DCE cleanup standard after 3 months of operation

1,2-DCE CONCENTRATION REDUCTIONS, 3 MONTHS OF OPERATION



IN-WELL STRIPPING AT NAVAL AIR STATION **DCE CONCENTRATION REDUCTION PROFILES** (note the logarithmic scale on the y-axis)



Operation Details

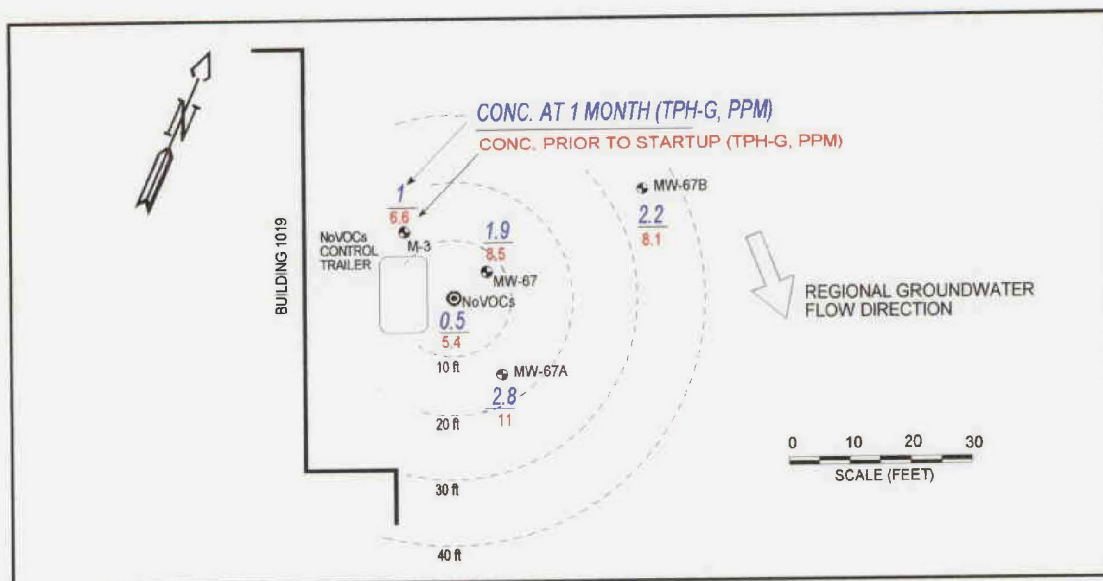
- ▶ 3 hp & 1.5 hp regenerative blowers
- ▶ Off - gas treatment - granular activated carbon
- ▶ pH control - automated acid metering system
- ▶ pH control system has effectively controlled iron precipitation/ fouling with virtually no maintenance
- ▶ Several monitoring wells to measure performance and radius of treatment zone
- ▶ At 5 gpm - air-to-water ratio = 75:1
- ▶ Mobile equipment trailer and process controls
- ▶ System operation has been in-service over 98 % of time with very limited inspection (system shutdowns have been due to power outages and flooding from hurricanes)

IN-WELL STRIPPING AT AIR FORCE BASE, WASHINGTON

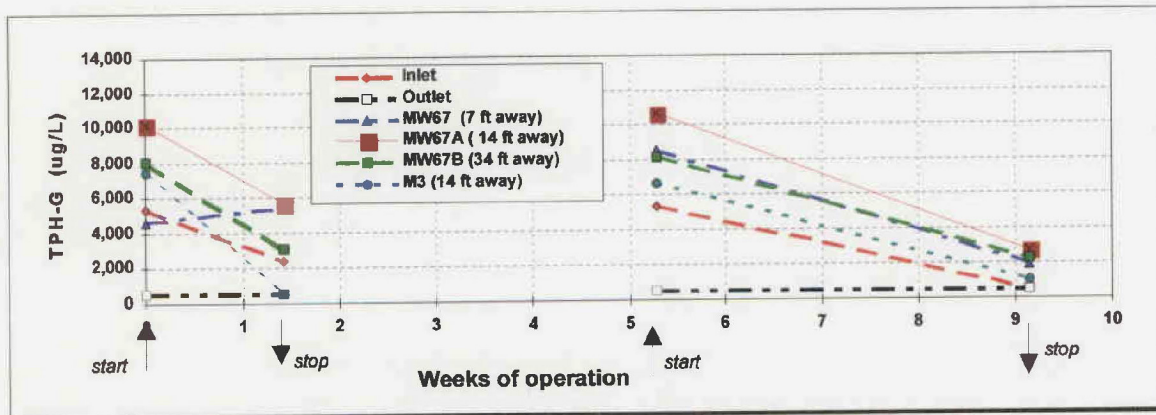
BTEX Case Study

Setting	Air Force Base, WA, Single well located in center of plume
Hydrogeology	Medium sand with silt, hydraulic conductivity $\sim 8 \times 10^{-2}$ cm/sec Saturated thickness - 4.6 to 5.8 feet Gradient - 0.0013 ft/ft Vadose zone thickness - ~ 8 ft.
Contamination	TPHg 10,200 ppb - Sheen observed; Benzene 5 ppb; Toluene 10 ppb; Ethylbenzene 237 ppb; Xylene 496 ppb
Inorganic Chemistry	Total alkalinity (as CaCO_3) - ~ 500 mg/L Dissolved iron - 20 to 80 mg/L
Operating Results	Pumping rate - 5 gpm Stripped VOCs in vapor stream - 12 to 25 ppmv Daily mass removal - 0.26 lb hydrocarbons/day TPH of NoVOCs recharge water at non-detect levels Average TPH reductions of 50 % in first operating week Radius of treatment zone greater than 5 times saturated thickness

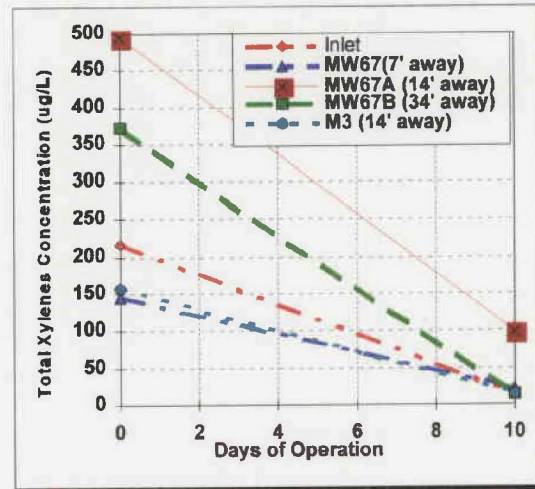
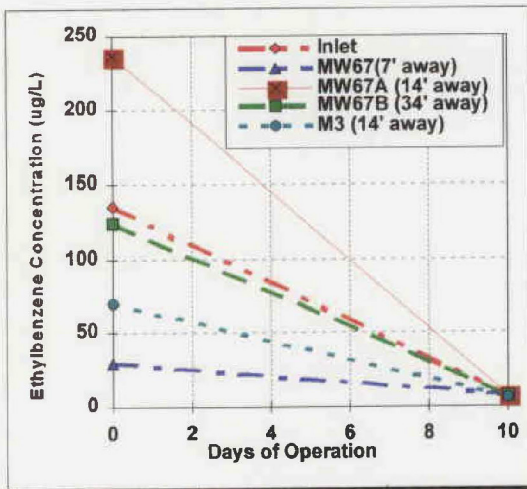
REDUCTION IN TPH-G CONCENTRATIONS AFTER 1 MONTH OF OPERATION



TPH-G CONCENTRATION REDUCTIONS



ETHYLBENZENE AND XYLENE CONCENTRATION REDUCTIONS



Operation Details

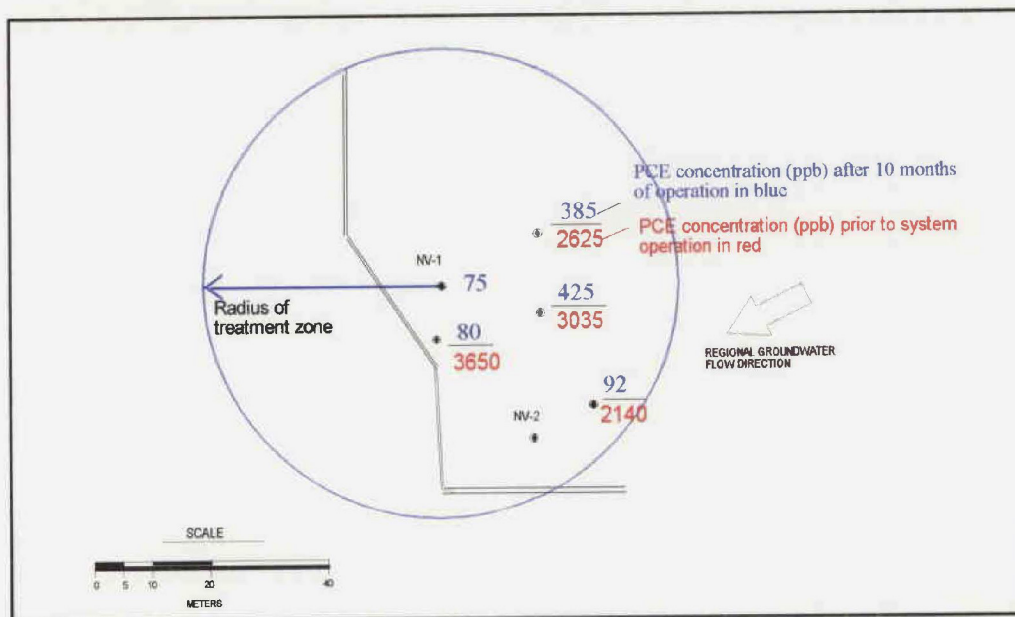
- ▶ 2 - 3 hp regenerative blowers, closed - loop operation no air emissions
- ▶ Off - gas treatment - granular activated carbon
- ▶ pH control - automated acid metering system
- ▶ 6 monitoring wells to measure performance and radius of treatment zone
- ▶ Mobile equipment trailer and process controls

IN-WELL STRIPPING AT A PIGMENT MANUFACTURING SITE

PCE Case Study

Setting	Pigment manufacturing site, France Two-well installation
Hydrogeology	Medium sand, hydraulic conductivity $\sim 5 \times 10^{-2}$ cm/sec Saturated thickness - 55 feet Hydraulic gradient - 0.007 ft/ft Vadose zone thickness - 8 ft.
Contamination	PCE - 3 ppm average initial dissolved concentration, peak concentrations as high as 23 ppm DNAPL presumed present Primary objective of hot-spot mass removal
Results	Pumping rate - 125 gpm NV-1, 60 gpm NV-2 Period of operation - 18 Months Radius of influence ~ 115 feet (35 meters) per well Maximum concentration reduction - 98% Average concentration reduction - 91% Total mass removal in conjunction with SVE ~ 4000 lbs of PCE

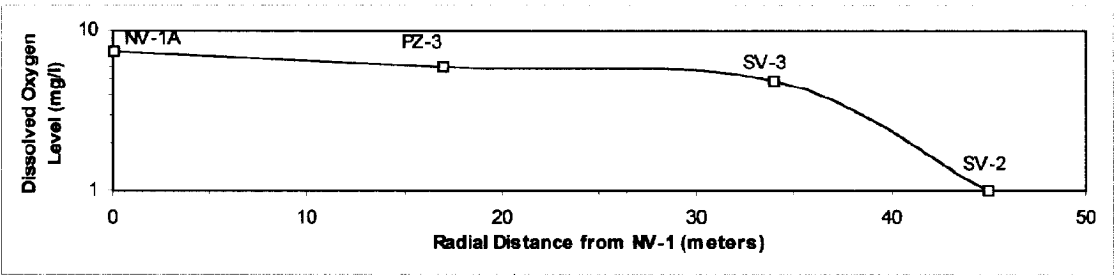
PCE CONCENTRATION REDUCTIONS AFTER 10 MONTHS OF OPERATION



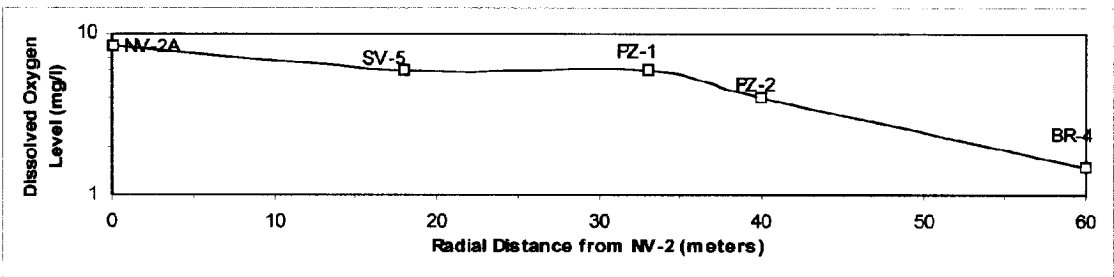
The predicted circulation zone for a recirculating well is an important system design parameter. The water recharged from the upper well screen well has dissolved oxygen (DO) concentrations in excess of the background DO found in most aquifers. Therefore, the distribution of DO in the aquifer can be used to demonstrate the extent of the area being treated by the recirculating well.

At this site the circulation zone for each well was measured by analyzing DO in groundwater after 10 months of operation. The extent of the circulation zone for wells NV-1 and NV-2 is approximately 35 to 40 meters (115 to 130 feet) in radius, respectively. There was a reasonable match between the design-predicted and measured circulation zones.

Radius of Treatment Zone from Recirculating Well NV-1



Radius of Treatment Zone from Recirculating well NV-2

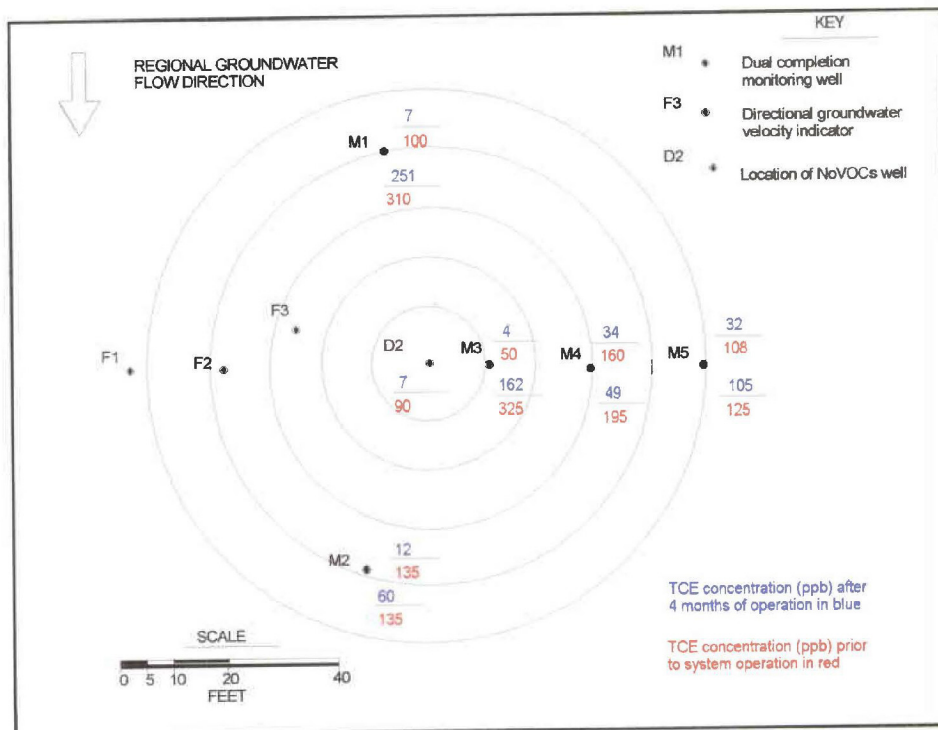


IN-WELL STRIPPING SYSTEM AT AIR FORCE BASE IN CALIFORNIA

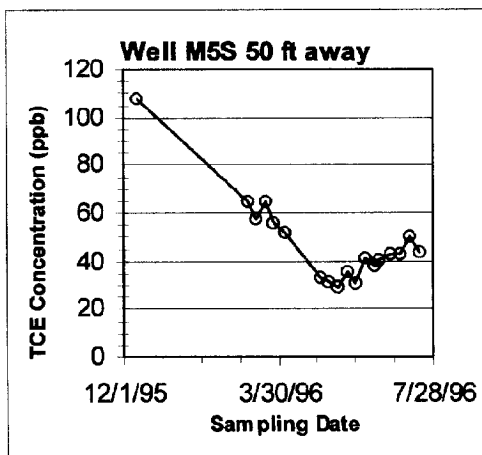
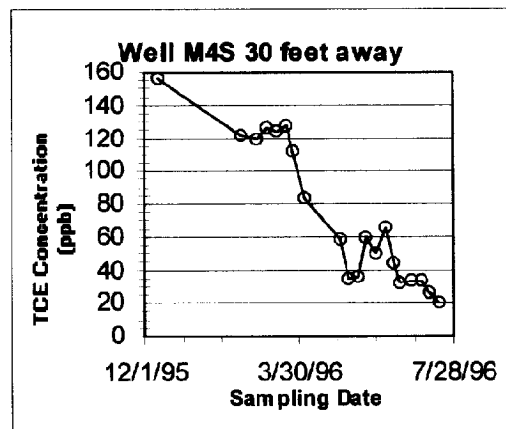
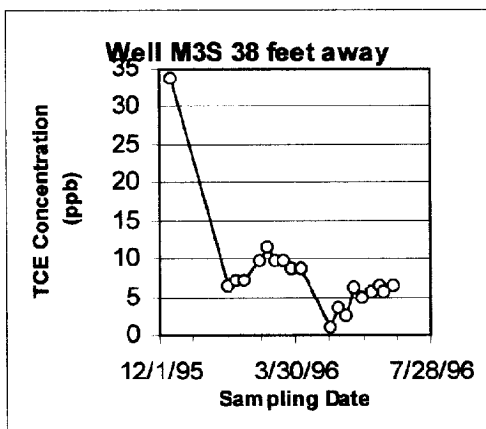
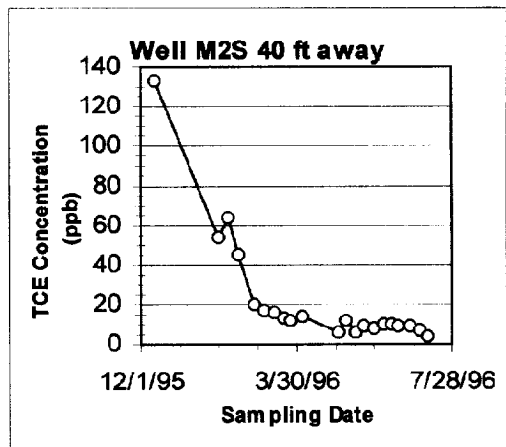
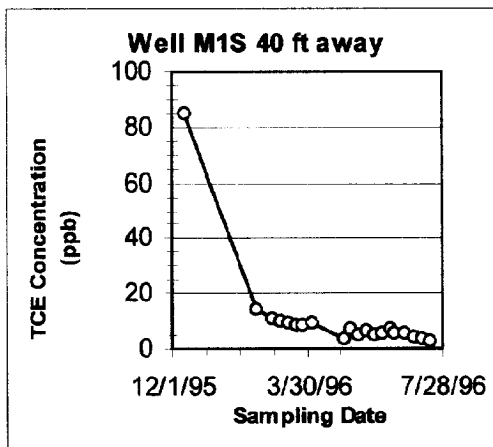
TCE Case Study

Setting	Air Force Base, CA Technology Demonstration Site
Hydrogeology	Sandy silt/silty sand Low yield aquifer ~ 1×10^{-3} cm/sec Saturated thickness - 23 feet Hydraulic gradient - 0.0047 ft/ft Vadose zone thickness - 27 ft.
Contamination	TCE - 300 ppb initial
Inorganic Chemistry	Alkalinity- 288 ppm as CaCO_3 , groundwater is in equilibrium with calcite (strong potential for scaling)
Results	Pumping rate - 3 to 8 gpm Period of operation - 7 Months Radius of treatment zone - >50 feet, more than 2 times plume thickness Average concentration reduction at 4 months ~ 67% Maximum concentration reduction - 97%

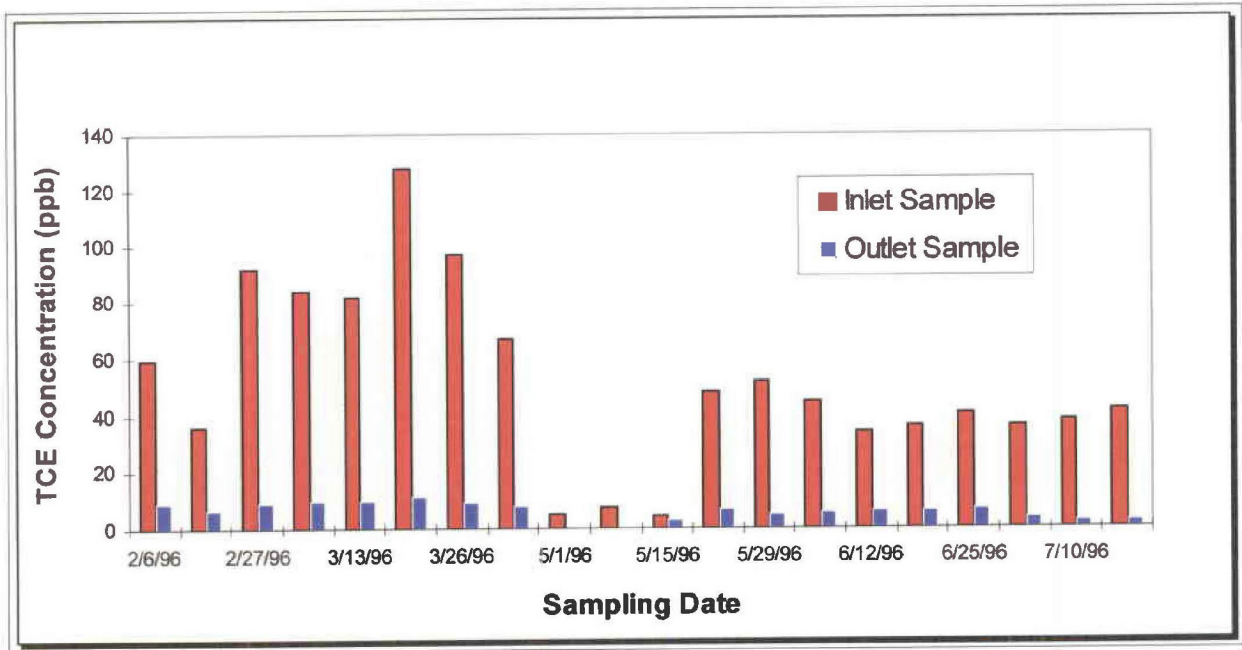
INITIAL CONCENTRATION REDUCTIONS



Contaminant Concentration Reduction Profiles - AFB in CA



In-Well Removal Efficiency, AFB in CA



Operation Details

- ▶ 3 - 1.5 hp rotary vane blowers
- ▶ Closed - loop operation - no air emissions
- ▶ Off - gas treatment - granular activated carbon
- ▶ pH control - carbon dioxide addition to injected air
- ▶ 6 monitoring wells to measure performance and radius of treatment zone
- ▶ At 8 gpm - air-water ratio = 55:1
- ▶ During system demonstration period of 7 months, 4 of 6 shallow zone monitoring wells reached 5 ppb MCL for TCE
- ▶ Average single pass removal through the stripping well of 90 %
- ▶ Flow sensors showed significant hydraulic influence (changes in vertical and horizontal flow directions and velocities) at all points monitored (at least 35 feet from the stripping well)

PILOT TESTING OF IN-WELL STRIPPING PROCESS

Laboratory Setting

Laboratory pilot testing of in-well stripping process, conducted by Battelle Northwest Laboratory.
Full-scale well (70 feet column, 6-inch diameter) constructed in lab

Contamination

1,1,1-TCA introduced to a tank at two concentrations; one test at 410 ppb and one test at 259 ppb.

Primary objective of the pilot test was to verify the mass transfer through in-well stripping process and validate design parameters

Operations and Results

The pilot system was operated at a relatively low air-to-water ratio (6:1, due to equipment limitations) and achieved a removal efficiency of approximately 65% of the TCA concentration per treatment cycle. The engineering calculations used to predict stripping efficiency were demonstrated to be accurate. The stripping efficiency can be easily increased to >90 % by simply increasing the air-to-water ratio to greater than 20:1.

Results of In-well Stripping Pilot Testing for 1,1,1-TCA Removal

